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STUDY OF THE HUMAN ELEMENT IN FUTURE ANTI-BALLISTIC MISSILE SYSTEMS

Summary Report

By D. W. Conover
Human Factors Engineering Group

CONVAIR SAN DIEGO   CONVAIR DIVISION   GENERAL DYNAMICS CORPORATION

ZG-017
31 December 1960

61-2-1
XEROX

Office of Naval Research
NOnr 2953(00)

Advanced Research Projects Agency
ARPA Order 5-58 Task 9

STUDY OF THE HUMAN ELEMENT IN FUTURE ANTI-BALLISTIC MISSILE SYSTEMS

BY DONALD W. CONOVER
HUMAN FACTORS ENGINEERING GROUP

PART 1 - FINAL SUMMARY REPORT

224400

CONVAIR SAN DIEGO CONVAIR DIVISION GENERAL DYNAMICS CORPORATION

ABSTRACT

This is the final summary report on work performed under ONR contract NOnr 2953(00) in support of ARPA Order 5-58, Task 9. This task, and the covering ONR study contract, are concerned with the probable roles of man in future anti-ballistic missile (ABM) systems.

Present ABM system concepts were reviewed in order to make a detailed examination of the functions which man is expected to perform in these systems. Initial efforts in this study program, presented in a classified progress report dated 15 July 1960, were focused upon an analysis of the man-machine relationships in the Nike-Zeus system. This was done to develop a basis from which to extrapolate human factor considerations to systems of the future. In order to keep the contents of this document unclassified, a summary of the human role in current and proposed future systems is treated in a general way, without reference to specific system configurations.

A preliminary model of a hypothetical ABM system is presented as a frame of reference. It is within this frame of reference that subsequent efforts will be undertaken in the development of system element requirements along behavioral dimensions common to both men and machines.

Specific attention is focused upon the role of man in the command and control of ABM systems, the human function in system maintenance, and the human role in the management of system development programs. This report also suggests the broad outlines of a comprehensive design guide for the integration of man and machine in ABM system development, and sets forth in some detail a number of research problems related to man-machine interactions. The solution of these problems is crucial to the effectiveness of future weapon system developments.

P R E F A C E

The study program described in this report was carried out under Contract NOnr 2953(00) to the Office of Naval Research (ONR), with Dr. Paul G. Cheatham, ONR Code 455, acting as program monitor. The study, concerned with the functions that man may be expected to play in advanced anti-ballistic missile (ABM) systems, is a part of a much broader effort by the Advanced Research Projects Agency (ARPA) with the title of Project Defender. Project Defender is one of the major efforts being conducted by the Department of Defense in the ballistic missile defense area. ARPA Order No. 5-58, Task 9, which calls for an investigation of the human role in future ABM systems, comes under the general cognizance of Mr. Richard Lilly of ARPA.

Through the efforts of Mr. Lilly and Dr. Cheatham, Convair San Diego's activity under Task 9 will be coordinated in the future with complementary work being done by the Stanford Research Institute (SRI) and Bell Telephone Laboratories (BTL) on the tactical employment and communication problems, respectively, in future ABM systems. The work accomplished by BTL and SRI was carried out under Contract DA-024-200-ORD-1019 which covers ARPA Order 39-60, Tasks 9 and 14.

This report has leaned heavily upon the BTL and SRI work for much of the supporting factual material concerning the operational context within which man will function in future ABM systems. Special acknowledgment should be made of the technical support and ideational contributions given by Mr. M. Paul Wilson of BTL and Dr. Irving Yabroff of SRI.

The overall task of the program as first envisioned appeared to be well structured and quite specific in terms of stated objectives and requirements. However, as the program progressed through its initial phases, a change of emphasis seemed to creep in despite the efforts of project personnel to maintain an orientation toward the rather global nature of the problem. As the volatile and rather unstructured nature of ABM systems planning began to unfold, more limited goals emerged.

At a joint ONR-ARPA conference which convened at the Pentagon early in 1960, representatives from Convair, BTL, SRI, ARGMA, ARPA, ONR, and other groups concerned with the common problem of defense, met to discuss objectives and to clarify goals. Among the various decisions made, the more far-reaching ones, in terms of Convair's effort, were those related to plans for cooperative efforts among the several groups and a clarification of the subgoals concerning man's role in future ABM systems.

Specifically, the goals outlined in Chapter I of this report stemmed from the ONR-ARPA conference and resulted in focusing major attention during the program on the role of man in his possible command and control function in future systems. Thus, the major portion of Convair's effort is more clearly identified with requirement-setting studies and initial attempts at system model building. At mid-year an agreement was reached between the ONR Program Monitor, Dr. Cheatham, and the Convair study group to conduct four interrelated but functionally separated studies on man's role in ballistic missile defense. They were a summary report, an annotated bibliography, a detailed description of current ABM systems, and research problem suggestions. This document is the unclassified summary report of the total effort undertaken during the past year. The three other reports will be available for distribution to interested groups through ONR, Code 455. They are entitled as follows:

1) - Study of the Human Element in Future Anti-Ballistic Missile Systems - An Annotated Bibliography. Convair Report ZG-018, by E. N. Kemp and P. B. Hall, (31 December 1960) (U)

2) - Study of the Human Element in Future Anti-Ballistic Missile Systems - System Descriptions. Convair Report ZG-019. By D. W. Conover, W. E. Woodson and E. N. Kemp. (31 December 1960) (S)

3) - Study of the Human Element in Future Anti-Ballistic Missile Systems - Suggested Research Problems. Convair Report ZG-020. By W. E. Woodson and D. W. Conover. (31 December 1960) (C)

In order to keep the contents of the final summary report unclassified and to make it available for wider distribution, ABM system details have been treated in a general way without reference to specific equipments or operational configurations. Convair Report ZG-019 (Secret) contains a summary description of specific ABM subsystems.

The amount of up-to-date human factors engineering information gathered is disappointingly meager in view of the extensive efforts going on in ABM systems planning. However, this paucity of information was not unexpected since much of the current work on active ABM defense systems has advanced little beyond the feasibility study or conceptualization stages. On the other hand, the information which was made available, and which was subsequently analyzed, provided a workable basis upon which to generate a number of reasonably justifiable predictions and conclusions as to man's probable role in future systems. Suggested future studies, outlined in some detail in Convair Report ZG-020, should focus attention on specific man-machine problems requiring immediate attention, especially in the areas of command performance, decoy discrimination, electronic counter-countermeasures, system maintainability and design for safety.

Material which might be considered proprietary has been eliminated from consideration in the preparation of this report. The material which formed the basis upon which threat data were assessed was largely unclassified and any inferences which may be drawn from this report about the specific nature of the future ICBM threat to the United States are based on well documented sources available to the general public.

Individual contributions to specific sections of the report by outside individuals or groups are acknowledged at proper places within the body of the report. References are numbered sequentially throughout the entire report. In order to follow the subject-oriented format used in the annotated bibliography, Convair Report ZG-018, titles of references used in this document are given prior to the author's name.

A list of all the organizations and individuals whose contributions made this report possible would be a document within itself. However, a number of them besides BTL and SRI, mentioned previously, deserve special mention: The Federal Electric Company of Paramus, New Jersey, for making possible a trip to the DEW line; the Air Defense Command and NORAD for their cooperation in arranging field trips to various Air Force installations; personnel from BMD, STL, WADD, HumRRO, ARDC, ARGMA, RADC, and CCDD for their review and critique of the many ideas and concepts expressed herein; Dr. Fred Ireland of RCA for his timely information on BMEWS human factors problems; Mr. Paul Atkinson of Philco and Dr. John Manglesdorf of Lockheed for information on satellite surveillance systems; Dr. James Degan of MITRE Corporation for his suggestions on the personnel subsystem program; Lt. Col. R. L. Bottoms of CCDSO for his critical review of portions of this document; Dr. Stanley Deutsch of Douglas Aircraft for information on terminal defense manning problems; and personnel from Headquarters, USAF, DCS/Operations for their willingness to review certain weapon system management concepts expressed by the author of this report.

The author also wishes to acknowledge the specific contributions made to this report by members of the Convair study group: Tillman Schafer for his contribution to the systems model and to the chapter on maintainability; Eugenia N. Kemp for her support in editing the entire manuscript; Wesley E. Woodson, Human Factors Engineering Group Supervisor for his many contributions in every chapter in the report; and Patti Hall and Sharon Robins for their untiring efforts in maintaining the file of documents reviewed during the study program and for typing this report.

CONTENTS

I N T R O D U C T I O N

The study effort under contract number NOnr 2953(00) was directed toward developing a frame of reference within which predictions could be made of man's useful functions in future anti-ballistic missile (ABM) systems. This report presents a summary of the ABM defense system concepts investigated under an Office of Naval Research (ONR) project, suggests the broad outlines of a man-machine systems design guide for development of future ABM systems, and sets forth a number of problems related to man-machine interactions as their solutions will be crucial to the effectiveness of future ABM systems.

A more explicit statement of the problem investigated is presented in the following section. The general objectives of the study are then presented; these are followed by a discussion of the extent to which these objectives were attained and the method of approach utilized to obtain them.

CHAPTER I

AIMS, OBJECTIVES, AND METHOD OF APPROACH

The studies called for in this program were necessary in order to provide a basis for assessment and prediction of the performance characteristics which may be required of the human operator in ABM defense systems of the future, specifically from 1965 to 1975.

Concurrent with a review of present ABM system concepts and a detailed examination of the functions which man is expected to perform in these systems, it was necessary that certain defense concepts be synthesized, that the ballistic threat for the time period under examination be considered and that communications, tactics, and employment concepts be reviewed in order to provide a matrix within which future systems could be evaluated.

In reviewing the various objective techniques which would aid this effort in evaluating ABM subsystem performance characteristics, it was decided to explore the utility of various analytic models which could be substituted, in a very general way, for the more objective world of simulators or systems conceived but not yet in being. The problems investigated in the present study stem from a growing concern by responsible individuals, both in the military and in industry, that the magnitude of the task confronting the designers of future ABM systems may be lessened considerably by a clear delineation of the functions that man should and must perform.

The crucial issues revolve around such questions as the amount of information man must have to perform effectively at every level of his involvement in the system, the modes whereby this information may be displayed, and the criteria upon which the information presented is judged as relevant to the decisions which must be made in order to accomplish the system mission.

There were four explicit goals of this study. The extent to which these goals have been met must be judged in the light of the highly futuristic and complex nature of the subject task assignment and on the extent to which relatively sparse data have been obtained on various ABM subsystems now in being or under active research and development programs. These goals may be summarized as follows:

1) - Analyze, in as much detail as can be made available during the first half of the study period, the human factors problems related to currently-planned ground-based attack systems, space-based attack systems, ground-based reconnaissance and warning systems, and space-based reconnaissance and warning systems.

2) - Develop an explicit subject matter outline and the concepts underlying basic guide lines to systems designers for incorporating man in future ABM systems, with emphasis being placed on those characteristics which may justify his inclusion in these systems.

3) - Develop a list of recommended research problems on specific topics related to the role of man in future ABM systems, the particulars of which will be spelled out in sufficient detail so as to form the basis for a specification of future study requirements in this area.

4) - Prepare an annotated bibliography of all available work in this area which may be of utility to other workers in the field, and continue the planned program of field trips and visits to agencies and facilities responsible for various aspects of anti-ballistic missile defense. The sub-goal of this latter activity was to collect, within one facility, pertinent information on the status of the human factors efforts on ABM subsystems in order to develop a comprehensive picture of the research activities under way, as well as to identify the problem areas not being covered.

One other aspect of the current program requires some explication at this point. The overall task as first visualized at the outset of the study effort appeared to be clean-cut and quite specific in terms of stated objectives and requirements. However, as the program progressed, a change of emphasis seemed to creep in despite the conscious efforts of project personnel to maintain a fixed orientation on the very global nature of the task. It became apparent within the very first few months of the study that what was first considered to be an attainable objective faded further into the background as the highly volatile and still unstructured nature of current ABM systems design details began to unfold. For example, a terminal defense system, which is today closer to production than any other system, still provides the human factors specialist with more unsolved problems in the utilization of man, even in the maintenance role, than it provides data for the project personnel upon which to base extrapolations to future systems. Thus, for the most part, the raw data and the externally-generated material upon which this report is based lies in the realm of proposals to conduct further research on various ABM system concepts, some preliminary design data on the Midas and Samos systems, parametric studies on space-based attack systems, partial human-factors-documented studies on the ballistic missile early warning system (BMEWS), information abstracted from a host of investigations on human decision making processes, display requirements, etc., studies on research methodology, studies related to the role of man in specific current systems, and digests of symposia and conferences on various human factors problems attended by individuals who were as much in the dark with respect to this crucial issue as those working on the subject project.

In-house activities included a review of Convair's own extensive efforts and program on ABM systems plus constant utilization of its files on research reports and studies in this very broad field. These are probably the largest and most complete files on ABM systems maintained by any industrial organization in the country.

In addition to a review of the literature available both within-house and that obtained from cooperating governmental and industrial facilities, field trips were undertaken by members of the project team to over twenty facilities responsible for various aspects of ABM systems development or management programs. In addition to these trips, a member of the project team made a tour of the distant early warning (DEW) line in order to gain first-hand insight into the activities of a complex system operating under hostile environmental conditions.

One final in-house activity which should be mentioned is that of model building. In considering the various objective techniques which might aid the program in evaluating future ABM subsystem performance characteristics, we decided to try our hand at model construction. The objectives in developing various models were to provide an instructive exercise in model building related to man-machine system synthesis, and to isolate certain subsystem functions wherein technical improvements (possibly man-related) might provide maximum payoff.

These early models of gross system performance would not serve to isolate human factors problems, but they might provide cues as to which subsystems should be given priority examination. In summarizing our reasons for this approach, it is believed that a probability analysis, like that initiated toward the end of the current effort and which we intend to carry on in greater detail with more sophisticated models during future studies, will aid in presenting technical arguments to cognizant military agencies. An analysis of this type clarifies logic, makes assumptions explicit, and focuses attention upon those crucial points or subsystems where information is disputed or lacking.

One other aspect of this study should be given the special emphasis it deserves before passing on to the main body of this report. The current program, which is essentially concerned with the role which man might play in future ABM systems, is but a part of a much more comprehensive effort conceived by the Advanced Research Projects Agency (ARPA), under the broad title of Project Defender. The purpose of Project Defender is to spell out future requirements related to the defense of North America against an enemy ICBM threat during the 1965-1975 period. Through the efforts of both the ARPA and the ONR project monitors, Convair San Diego's activity related to the role of man is now being coordinated with complimentary efforts by Stanford Research Institute and Bell Telephone Laboratories on the employment and communications problems, respectively, in future ABM systems.

Additional support for this and other supplementary studies has been provided through the assistance and cooperation of personnel from the U.S. Air Force Command and Control Development Division (CCDD) located at L. G. Hanscom Field, Bedford, Massachusetts, and from the Office of the Deputy Chief of Staff/Operations, Headquarters, U.S. Air Force.

This unique and cooperative effort between so many organizations, both civilian and military, has special significance, not only in terms of the overall objective of clarifying some of the problems which will confront the designers of future ABM systems, but also in terms of the impact it will have upon the development of more effective personnel subsystems management programs supporting these projected weapon systems.

The critical world situation and the ever-increasing complexity of our military systems combine to pose a problem of enormous magnitude upon our technology and our reserve of available manpower. It is in this latter area, maximum utilization of the limited manpower available to operate, command and control these systems, that significant and far-reaching improvements must be made if the political and military integrity of the United States is to be maintained in the face of the estimated Communist threat.

Present and projected technological improvements in military hardware threaten to outstrip our capabilities for manning and controlling these materiel developments. There is a profound lack of basic knowledge concerning the capabilities of man to interact with the systems now being planned, or in early conceptual stages. There is an even more glaring scarcity of knowledge about the capabilities of man to absorb, assess, and utilize the information which will be made available to him in a number of the super-command and control centers which are currently under consideration or which are already in the planning stage.

Thus, the broad outlines of the picture begin to emerge. The role of man assumes critical proportions. Automation will probably serve to relieve the burden on man of doing routine calculations on factual information, and will very likely assist him in assessing the complexities of the tactical and strategic situation. However, the likelihood of heuristic, self-adaptive mechanism developments capable of automatically programming themselves to handle events controlled by the enemy and which are largely unpredictable, seems somewhat unrealistic and quite beyond the state-of-the-art within the next twenty or thirty years.

Command decisions based upon qualitative as well as quantitative information will be required of man far into the foreseeable future. Thus, when the problem is defined as the pre-planning of future man-machine weapon systems, it becomes imperative, as has been so succinctly stated in a recent study on human decision making (1), to gain an accurate knowledge of the present weapon systems, the present limitations of their subsystems as they affect human performance, and the limits of human performance in systems which in turn will pose absolute constraints on future weapon systems. It is to this broad problem that we address ourselves in subsequent sections of this report.

CHAPTER II

ABM COMMAND CONTROL SYSTEM MODEL

The functions performed by man in present complex systems such as semi-automatic ground environment (SAGE) for continental defense against air attack or DEW line required analysis in order to establish some basis upon which to extrapolate his possible future role. On the other hand, it is necessary to ascertain what roles man can play in any complex system, independent of the constraints imposed upon him by present specific system design inadequacies. To this end a series of special sub-efforts were directed.

It was first necessary to clarify the meaning of the term ABM system. The concept supported in this study of the ABM defense system as an entity appears to be considerably broader than that seen by many present systems designers. What are often referred to as ABM systems are in reality only assemblages of equipments and men in sub-units of the total defense system. It seemed important to the project team to maintain a much broader perspective when looking at the human elements in ABM systems of the future so as not to be misled by the typical automation claim that there are no human problems because it is completely automatic.

As a result of this broader concept of an ABM system, it is mandatory to think of the system from the man out. That is, ABM defense is a responsibility which resides in a human being or an organized assemblage of humans. What these humans need to meet their responsibility turns out to be the system of which they are an integral part.

Logical development of the system proceeds from the needs of humans, i.e., information about a potential threat, a means of organizing this information, and the power to defend against the threat. With this philosophy in mind, it was assumed, for purposes of this study, that ABM defense is man-oriented and that it would not, during the time period under consideration, be fully automatic. It will, in fact, be ever changing, as dictated by the requirements of man to discharge his responsibilities.

A useful conceptual model, developed in the initial stages of this study, is shown in Figure 1. It presents a picture of the overall ABM defense system in the fundamental military paradigm of intelligence, organization, and application of force. Although this diagram may appear as an over-simplification of what is obviously a complex relationship, it serves the purpose of clearly delineating the major subsystems within which man may be involved in future ABM systems.

The general term ABM defense system includes the concept of passive techniques, which might conceivably be used in combination with, or which might become an alternative to, active defense. The expression, active ABM defense subsystem, encompasses all the subsystems and elements specifically associated with the task of ICBM destruction or de-lethalization through dueling intercept and some screening techniques. The term passive defense refers to means (such as dispersal, evacuation, hardening, or sheltering) which mitigate or avoid the effect of enemy nuclear bombardment without direct military action. Passive defense methods may be used to protect military as well as civilian and industrial target complexes.

The diagram shown in Figure 1 separates the ABM supra-system, for purposes of analysis and explication, into four major systems, each with clearly delineated missions and responsibilities. Subsystems functions and operations may well overlap between blocks; however, a logical taxonomy demands this structure.

Block 1 of Figure 1 represents the command and control function. The concepts involved in the specification of this functional area include those of national policy and political doctrines stemming from executive department and congressional actions, and military command and control functions (including communications, central data processing, threat analysis, and action orders). The military definition of command and

GENERALIZED ABM SYSTEMS MODEL

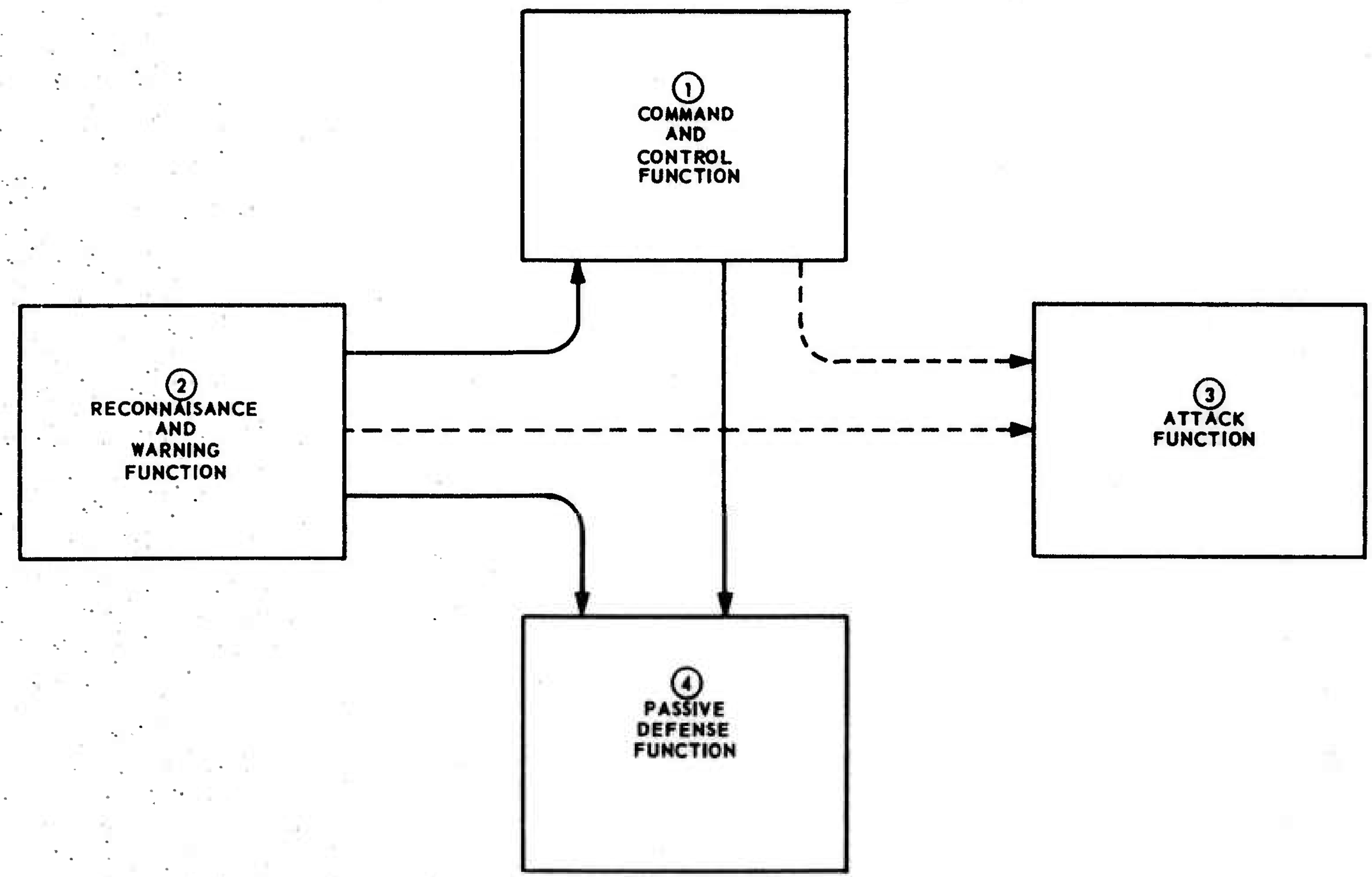

Figure 1

control systems (the L systems) is: those major systems which are used to collect, transmit, process, and display data required for timely decisions. Military commanders continually stress the importance of communications in global operations. Recently the Strategic Air Command (SAC) Commander, General Power, stated this concept very succinctly, "One cannot command without control, and one cannot control without communications."

Block 2 of Figure 1 represents the reconnaissance and warning functions and may be conveniently expanded to include the sub-functions of target acquisition, target data processing and filtering, and data transmission to central control, but excludes these sub-functions when performed by essentially autonomous, semi-automatic attack systems. The primary mission of an early warning and/or reconnaissance subsystem is to provide a maximum warning time in which to prepare for active defense against a confirmed or probable ballistic missile attack, and for evacuation of civilian populations to shelters or for dispersal from threatened areas.

Block 3 represents the functions performed by active attack systems operating as autonomous units, responding to a given target or class of targets in an essentially pre-programmed manner, subject only to a set of initial conditions or constraints which constitute the system threshold for action. Within this context, one of the few ways in which the Block 1 functions would interact with the Block 3 functions would be in countermanding the pre-programmed response to an adequate attack system stimulus, i.e., sensed, legitimate targets within range of its weapons. Operationally, this would be equivalent to a prior command decision or policy position not to attack certain detected, threatening ICBM nose cones, i.e., to accept the damage which would result from detonation of the warhead(s) in the non-defended area, depending only upon hardening, shelters, or dispersal for protection and minimization of damage.

Block 4 of Figure 1 represents all the functions performed by passive defense systems. In addition to the civil defense warning function, it includes the function performed through the mobilization, hardening, and dispersal of SAC bases, the functions performed by shelters, and the evacuation of the civilian population from threatened target areas.

The lines connecting blocks in Figure 1 represent possible relationships between functional areas. The solid lines constitute those relationships which appear to be clearly established in current operational doctrine and for which requirements are reasonably certain.

For example, the postulated command and control function requires inputs from reconnaissance and warning subsystems. The passive defense function, having inputs from the warning system (possibly routed through the command and control block) serves two purposes: (1) the passive defense measures undertaken by SAC bases, and (2) evacuation, dispersal, or sheltering of the civilian population. Conversely, the dash lines connecting functional areas represent relationships not yet clearly established or for which no requirements can be postulated in the foreseeable future.

On the other hand, interviews with North American Air Defense (NORAD) combat operations center (COC) personnel and statements abstracted from a survey of the literature on this topic suggest that the military does have an implicit requirement for exercising go-no-go control over the semi-automatic attack subsystems which have been designed, at least conceptually, for autonomous operation. This represents an area of uncertainty and controversy at highest planning echelons which may or may not be entirely resolved by research procedures.

The responsibility for making the final decision to attack incoming ICBMs and when to initiate that attack will continue to rest with man. The degree to which man will permit the discharge of these responsibilities to be completely determined by automatic processes is a moot question whose resolution may well rest upon executive policy decisions rather than stem from the results of research on the factors which constitute the elements in the decision matrix. Many factors must be weighed and evaluated in arriving at the final command decision to commit active attack systems against incoming ICBMs, if they are considered, in their most general case, as being weapon systems whose radius of action extends to, or over, enemy territory. These factors, for which quantitative measures may not be available, include political climate, state of world tension, unwillingness to initiate a nuclear holocaust, strategic or tactical value of threatened area, et cetera. Technological breakthroughs may modify the details of this problem, but only a marked change in the national military posture will alter the requirement for some form of final command decision by man before active attack (defense) is initiated against incoming ICBM warheads.

For example, the degree of autonomy which may be required for the currently-planned terminal defense system is postulated on the assumption that early warning may not be available. The decision-action time span for terminal defense systems is a direct function of the target acquisition range. Therefore, the delays involved in transmitting target information first acquired by weapon system radar and displaying it at a remotely located command center for threat evaluation and action-decision by the commander, would create serious control problems, since the time from initial detection of the warhead by target acquisition radar, to impact in the target area, is relatively short.

By providing,through advanced system developments, some estimate of enemy threat size and intended impact area within two or three minutes after enemy ICBM launching, warning times would be increased substantially and would permit the command and control function somewhat more latitude in exercising the prerogative of selecting alternate attack subsystems. Furthermore, if the national military posture included the policy of conducting a preemptive strike based upon positive intelligence information, the attack-defense and passive-defense subsystems would require preparatory alerting orders from central command and control in order to absorb the retaliatory strike capabilities of residual enemy forces.[1]

The diagram shown in Figure 2 presents a highly schematized arrangement of the command control relationships which we postulate will obtain among subsystems within the overall ABM defense organization of the future.

Through a comprehensive process containing elements of speculation, rationalization, synthesis, analysis, and an extensive evaluation of future system missions, the conclusion has been reached that this scheme covers most of the probable ABM defense system arrangements. Obviously, a very large number of arrangements could be devised which would cover the general case. For example, the structures could be categorized along the passive-active system dimension. However, for clarity in exposition, and to emphasize the topic of major interest in this report, man's role, the arrangement shown in Figure 2 was selected. Using this scheme as the basis upon which a subsequent system model exercise was conducted, a weapon command and control subsystem was abstracted from the general scheme.

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[1]The author of this report neither supports nor rejects a policy which includes the possibility of preemptive strike against a potential enemy. However, it represents one of many alternative military postures, the mechanism and details of which are legitimate factors to be given attention in considering the systems required for such action.

During the September, 1960 convention of the Air Force Association, Dr. Edward Teller, father of the H bomb, had this to say on the topic, ". . . .The United States never should and never will strike a preventative blow at the Reds. Hitting them first is wrong, immoral, and impractical. The United States must be able to absorb the first blow and strike back. This is the best way to make sure peace will be maintained. . . ."

ABM DEFENSE MODEL

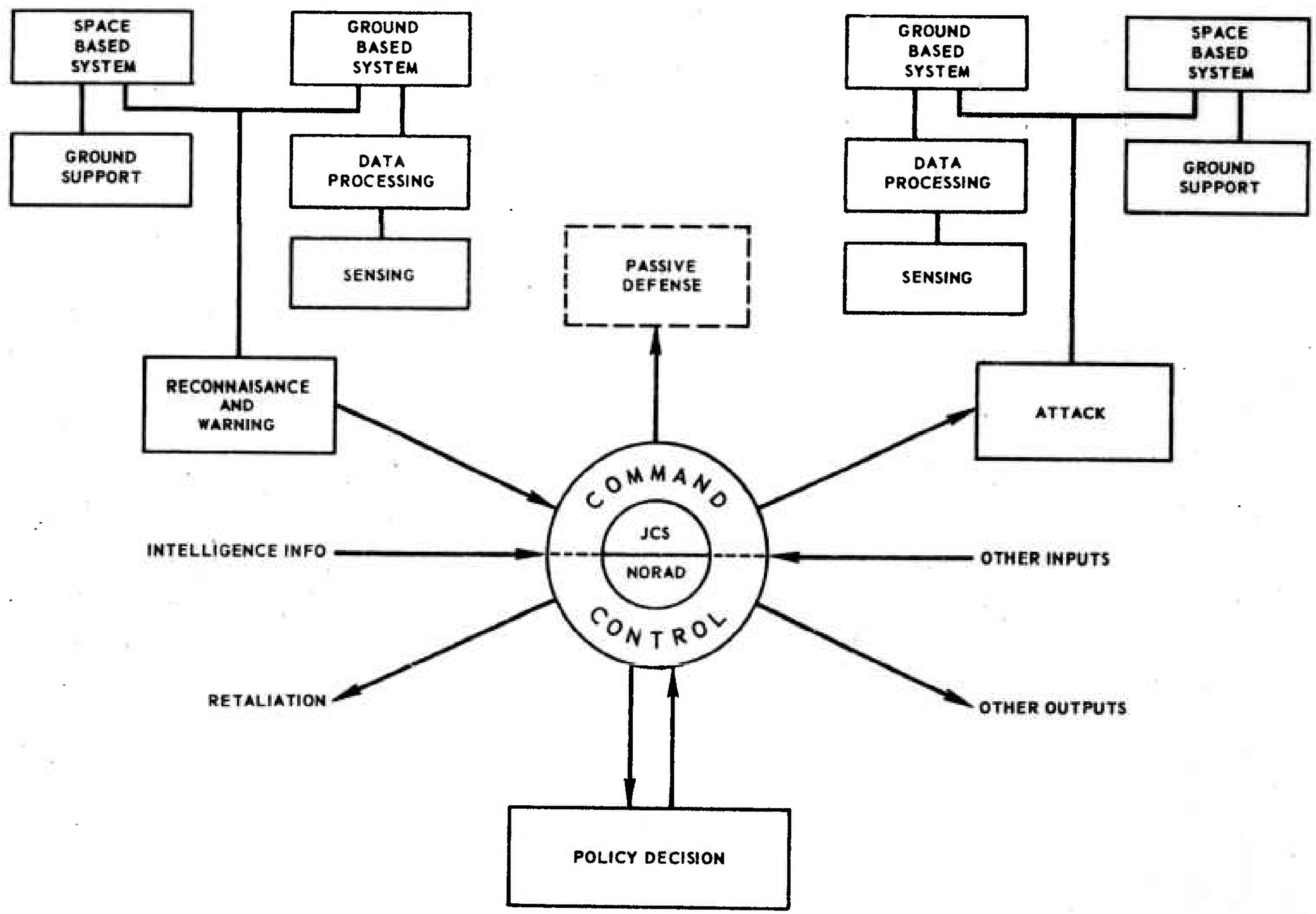

Figure 2

The mission selected for analytical treatment in the system model under discussion was that of terminal defense (a dueling game) against a fairly advanced two-salvo ICBM attack directed against strategic bases and industrial population centers. The second step was to specify the level of weapon subsystem task performance necessary for selected levels of mission accomplishment.

The four general functions which must be performed for the successful accomplishment of the ABM mission are: (a) surveillance, measured as probability of detection, (b) identification, measured as a probability of correct discrimination, (c) target/weapon pairing, measured as the probability of optimal weapon assignment, and (d) guidance, measured as the probability of reaching intercept point.

Probability of kill, in the model selected, was chosen as the measure of overall system performance. Task and mission performance constitute the dependent variables of the ABM weapon system. The level of performance obtained depends upon the system resources available and the environment in which the system mission is performed.

The system designer in the real world, and the analyst in the realm of models, has some control over the major categories of system independent variables. These variables fall within the two major categories of man resources and machine resources. Man's capabilities, perhaps not yet fully mapped or understood, are relatively limited. The utilization made of him and the degree of pertinent training to which he may be exposed constitute the major mechanisms for manipulation of the human resource. In one sense, at least, these specific mechanisms for manipulation apply to machine resources also. That is, machines may be organized in different ways, and they may be utilized more or less efficiently. However, there is a significant difference among the machine resources for offense and defense which carries rather subtle implications for the human resource manipulator. Improvements in weapon state-of-the-art, whether gradual or as the result of a major breakthrough in basic sciences, must always be considered along the offensive - defensive dimension. A fact of life with which man must contend is that defense capabilities generally lag offensive capabilities. The point of view which is being developed here is that the systems built or under development are tools for extending man's basic capability to manipulate his environment. The end result of this implied leapfrogging is usually a battle of man's wits wherein opposing machine systems cancel each other, leaving man to suffer for his own errors of judgment. Acceptance of this assumption leads to the conclusion, among others, that a key factor in the operational effectiveness of a weapon system is the extent to which its employment can be controlled by highly skilled men to meet the tactical situations as they develop in a combat environment largely dictated by enemy actions. It is in this context that the command/control function portion of a terminal defense system was chosen as the operation to examine in exercising the model previously mentioned.

Having outlined very briefly the dual problems of specifying system characteristics required for mission accomplishment, and predicting the performance characteristics of given components, the research problem of constructing and exercising a system model will be considered next.

The model is not to be viewed as the final product of this research, but rather as a necessary step in the development of a weapon system integration model which includes the system's human elements, defined in terms of dimensions which are relevant to subsystem task performance. Any model, from an equation to a complex, computerized simulator, is an abstraction of the real world. Since empirical validation of future systems is impossible, correspondence of the model with the system-to-be depends largely upon the sophistication of the analyst and the completeness with which he can specify system inter-relationships.

The problem of abstracting the real world has many ramifications. This abstraction may be accomplished at many levels, the lowest of which relates to the primary question of whether the overall system concept, regardless of its detailed, fine structure, is oriented in the direction of mission accomplishment. In attempting to find a solution to this problem, the present program was limited to an examination of overall organization effectiveness, with certain broad constraints placed upon a terminal defense system command and control function within a likely combat environment. Such a model will not serve to isolate human factors problems, but it does provide cues as to which subsystems demand further analysis.

Figure 3 portrays a logical tree representing successive binary events that occur when a missile defense system surveys a volume of space occupied by a single member of a swarm of warheads and decoys.

The object is, in fact, either a warhead or a decoy. Natural objects are excluded from consideration here because they can, in principle, be properly classified in every case on the basis of velocity. If the object is a warhead, the process, as represented in the diagram, goes through the transition 0-1. The probability of this transition, p_{01}, is controlled by the attacker. A warhead is detected with probability p_{13} and is not detected with probability q_{13} (or $1-p_{13}$); similarly for other steps in the processing of information on a warhead.

The probability that the object is a decoy, p_{02}, is $1-p_{01}$ which is equal to q_{01}; similarly, for the succeeding steps in the processing of information on a decoy. Note that all decoys are dead; the only difference among decoys is that some of them force the defense to expend a weapon, as portrayed by transition from state 6 to state 8.

The many factors which govern the probabilities attributed to the several states portrayed are not treated in detail in the preliminary model (2). This aspect of the model building activity represents the crux of future programs.

In the analysis of the problem, two cases must be distinguished; Case I, wherein the number of objects that are classified as warheads is greater or equal to the number of weapons available to the defense to be fired against them, and Case II, wherein the number of objects that are classified as warheads is less than the number of available ABMs. Both cases were treated, although it is considered to be more likely that Case I will obtain in the operational situation.

PROBABILITY MODEL FOR BALLISTIC MISSILE DEFENSE

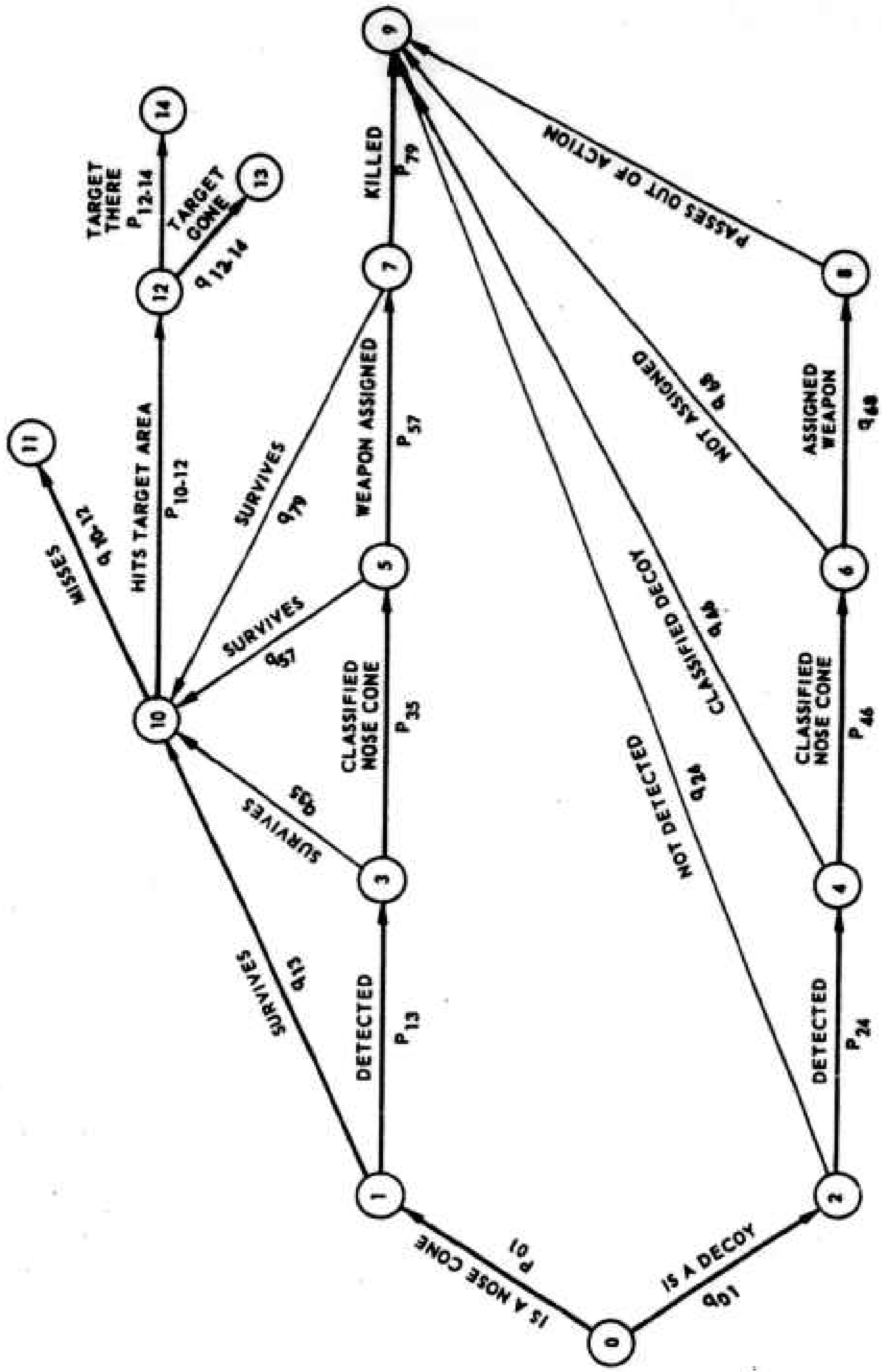

Figure 3

Let the number of reliable weapons available to the defense be designated c; then the probability of assignment of a weapon to successive objects is p_{57} until the number of objects inspected, detected, classified as a warhead and assigned a weapon equals c. Above this number the probability of assignment is zero.

The number of warheads entering the defended zone among a total of n objects is $(p_{01}n)p_{13}p_{35}p_{57} = np_{07}$. (1)

The number of decoys assigned weapons is: $(q_{01}n)p_{24}p_{46}p_{68} = np_{08}$ (2)

The number of weapons assigned to members of a swarm of n objects is: $n(p_{07} + p_{08})$, and (3)

when this number is reached: $n_0 = \dfrac{c}{p_{07} + p_{08}}$ (4)

the ABMs of the defense are exhausted.

Of the np_{01} warheads among $n-n_0$ attacking objects, $n_0(p_{07}p_{79})$ are killed and $np_{01} - n_0(p_{07}p_{79})$ survive.

The probability that a surviving warhead hits the target area is p_{10-12}. This probability depends upon the accuracy and yield of the ballistic missile warhead and the hardness of its intended target.

The probability, p_{12-10}, that the actual target is at the intended impact area when the warhead strikes, depends upon whether the target is mobile, how fast it can move, how much warning is given, and whether it is commanded to move (this latter decision being based, in part, upon detection and classification probabilities).

The kill probability for an individual warhead surviving attack is:

$p_k = p_{10-12}p_{12-14}$. (5)

The probability of kill for warheads attacking the same target is:

$p_w = 1-(1-p_k)^w$. (6)

The expected number of warheads attacking each target, if there are t targets, is: $w = (np_{01}-n0_{p07p79})/t$. (7)

The expected number of targets destroyed, m, is equal to t_{pw}. (8)

An analysis was carried out for both Case I and Case II using hypothetical threat data, the details of which are not germane to this presentation. The threat data were synthesized after a considered evaluation of the likely ICBM threat during the 1967-1970 period. Calculations were made for the number of targets destroyed in spite of the ABM defense activity. Note that in using the number of surviving missiles per target for the value of w, it was assumed, for the sake of simplicity, that surviving warheads are uniformly divided among the targets. This is not necessarily true, and also the relation between probability of kill and the number of warheads is non-linear. However, the theory was kept non-statistical for simplicity, since the intent in employing this model was not only for the purpose of predicting overall system effectiveness, but also as the basis for future isolation of critical subfunctions, wherein man's role in future ABM systems might be examined in more detail.

The results for Case I (about seventy percent of ground targets destroyed) are disappointing to the defense, despite the remarkably fine performance assumed for the active terminal defense system. For Case II (which assumes the defense has sufficient ABMs - i.e., knows how many ICBMs the enemy will deliver, and their characteristics) the results are relatively satisfactory to the defense. Referring to equation (1) and to the preceding definitions, it is clear that the only way of improving the active defense by any substantial amount is to improve discrimination, i.e., reduce p_{46}. Whether this can be done is both a technical and an economic problem which may be related to the utilization of man in the system as well as to improvements in hardware.

Whether the effort expended on active defense at any given level of p_{46} is as well spent as for improving hardening or mobility (or other passive measures) is a question for operational analysis, or for a policy decision at highest echelons.

In summarizing the rationale for this approach, it is believed that a probability analysis like the one outlined above may aid in presenting technical arguments to the military, because it clarifies logic, makes assumptions explicit, and focuses attention on those crucial factors where information is either disputed or lacking.

For purposes of detailed analysis in future studies, both man and machine must be described in terms of characteristics relative to the performance of weapon systems missions and tasks. It is also assumed that all tasks must be performed at or beyond some critical level in order to accomplish missions.

Referring again to the major issue of concern in this section, the command and control function, it is obvious that each of the subfunctions must be specified in objective terms, all being quantifiable along dimensions which are relevant to mission performance.

The diagrams shown in Figures 4, 5, and 6, indicate some of the factors which must be considered in the succession of steps required in arriving at the relationships which must be specified between man and machine dimensions and mission performance. Note,that at this level of specification the model is severely limited in its applicability as a guide for specifying human factors design requirements for future ABM systems. This situation represents the degree to which most human factors data and specifications are made available to the systems designer. And it is to rectify this state of affairs that this study effort, along with a number of other current programs, is specifically directed.

The three complimentary diagrams (Figures 4, 5, and 6) are presented to show some of the steps that must be taken in progressing from a list of system subfunction statements to the various characteristics of equipments, whether they be man or machine, required to carry out these activities. At each stage in the task of abstracting the elements comprising a weapon system, the formidable job must be undertaken of developing operational definitions which are measurable in common dimensions of man and machine behavior.

It may be illuminating to note (see Figure 6) in listing the possibly

MODEL OF A REPRESENTATIVE COMMAND/CONTROL FUNCTION IN A TERMINAL ABM DEFENSE SYSTEM

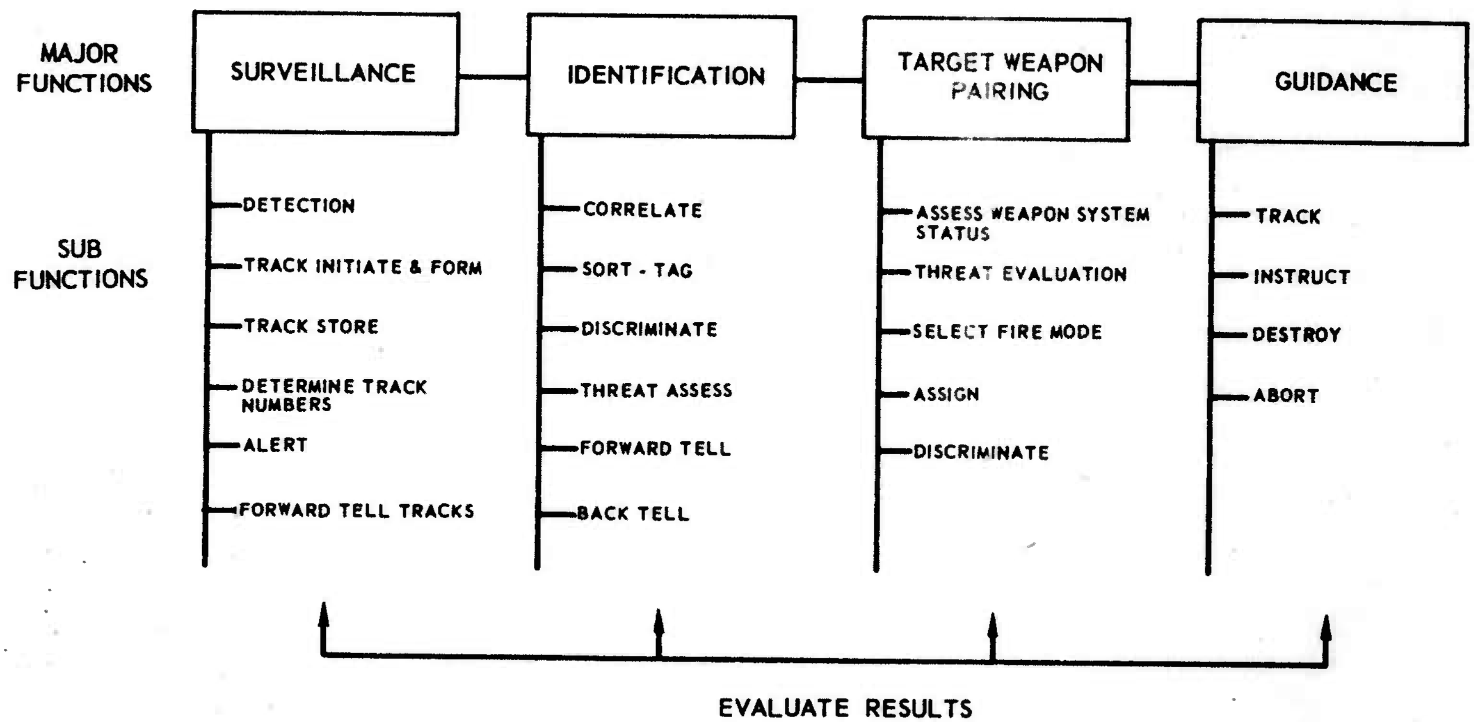

Figure 4

SOME CRITERIA FOR SUB-FUNCTION EVALUATION

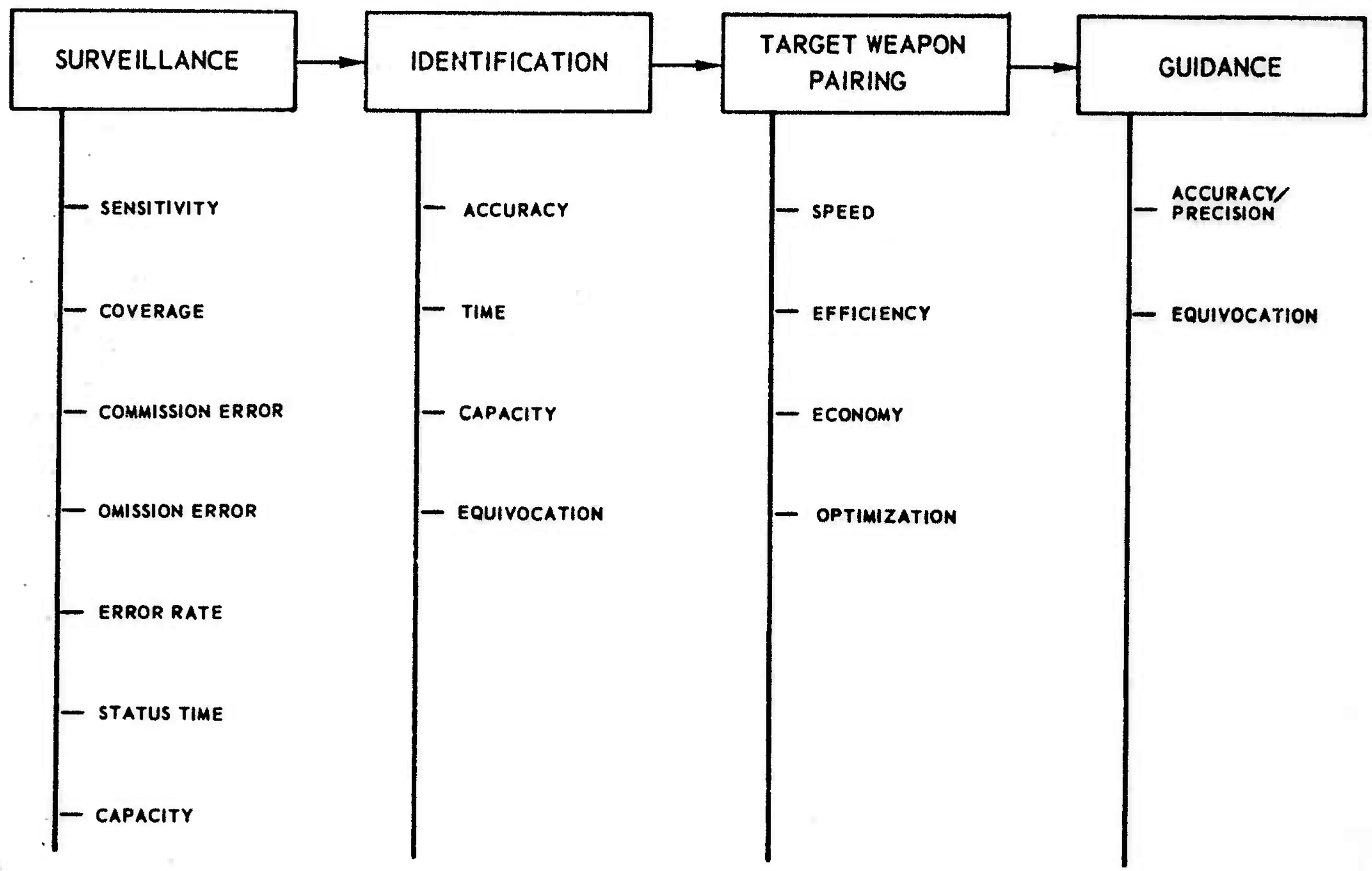

Figure 5

SOME UNIQUE HUMAN CAPABILITIES APPLICABLE TO COMMAND/CONTROL TASK PERFORMANCE

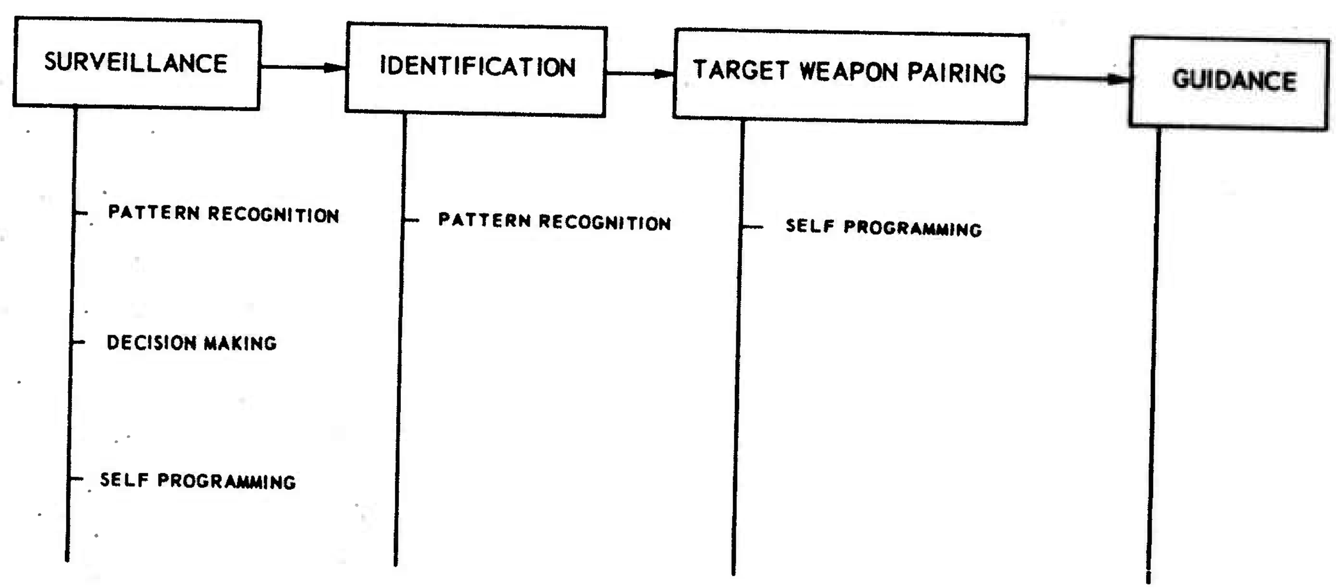

Figure 6

unique characteristics attributable to human beings, that they progressively decline from utility in the surveillance function to the vanishing point insofar as they make direct contribution to the guidance subfunction of an advanced ABM terminal defense system.

Successive backward steps in making this transition, the first step of which was undertaken in the current effort, include: (1) the development of an objective measure of overall subsystem performance, (2) the development of criteria against which these performance measures can be evaluated, and (3) the development of objective measures of pertinent human skill (and performance characteristics) dimensions and comparable machine skill dimensions.

Substantial amounts of data have been produced on human resource characteristics by workers in universities, government agencies, and lately, in industry. Much of this information is compiled and available in the form of handbooks, design guides and human engineering check lists. One of the more recent and comprehensive handbooks covering this general field lists in its appendix a suggested human factors design guidebook shelf of nearly thirty documents, each of which offers broad coverage on the characteristics of the human resource (3).

The problem facing the designer is one of deciding the relevancy of the masses of data available to him, and predicting the consequences of human capabilities and limitations on task and mission performance. Most human factors research has concentrated its efforts at the components level, leaving systems problems to be answered by extrapolation from components data. Man-machine interaction data are needed within specific system configurations.

Unless these data are collected in the field, or until suitable models of human behavior can be inserted into overall system analytical models, much of this information will have to be generated in a simulated system context which provides for the interaction of man-machine components. Current studies on the general problem of performing human engineering analysis of weapon systems are producing results which offer promise of integrating the analysis of a system's human elements with that of the overall system analysis (3, 4).

In its present stage, the design model of an ABM system suggested in this report specifies gross relationships which are believed to be important, and for which measures of variables and functional relationships will be sought in subsequent studies.

As was pointed out elsewhere in this report, there have been very few studies of command performance requirements. According to the authors of an excellent survey study on this topic, the dearth of studies on command performance may be attributed to the following reasons: "First, in studies of one-man systems all of the functions merged in the same man. Consequently there is much less need for explicit specification of requirements for coordination of tasks related to different parts of the total system. Second, many performance requirement studies are oriented as if there were a fixed set of performance tasks to be accomplished - essentially error-nulling tasks - with no major action alternative available. Consequently, the tactical command aspect of performance is not given much emphasis." (5).

Despite the many gaps which exist in an adequate methodology of requirement - setting studies for the manned aspects of systems, the model described herein and many others in the development stage will have applications in the organization of weapon system research.

Up to this point, in presenting the general command and control system model, the discussion has been focused on generalities related to system mission, analytical models, and the development of system-element requirements along behavioral dimensions relevant to task and mission performance.

Attention will now be centered upon a hypothetical ABM defense system of the near future. Figure 7 represents a highly schematized diagram of the lines of communication and data flow in such a system.

The analytical tools for systems analysis which were discussed previously are needed to determine how the human elements fit into and affect the overall system and how the overall system affects its human element. Subsequent studies will attempt the task of analyzing the organization described in Figure 7 as a vehicle for illustrating the application of current and forthcoming developments in system models as analytical tools.

An attempt has been made to depict the functional relationships in a time-after-launch/decision-responsibility-level, two-axis diagram. The time axis extends for some unspecified period of time prior to launch of ICBMs by the enemy to some few minutes after impact of the non-intercepted warheads in their target areas. The decision-responsibility axis extends from purely routine activities to policy-making levels. The block showing the SAC function (hypothetical) is included to show the relationship which may exist between it and the reconnaissance and warning function only, and does not include the possible retaliatory function of the SAC.

Note that the central group of blocks denote simultaneity of action, and for all practical purposes, the policy-level decision is available to command and control at almost the instant of threat assessment and evaluation. The reconnaissance and warning function has played its role by indicating alert level, notifying SAC, providing the basis for the autonomous attack system action, by supplying data to the centralized command post in essentially one continuous process. Through the communication and data processing function, the passive defense functions and the policy decisions are implemented. ICBMs penetrating the automatic space-based attack systems are subsequently engaged by terminal defense systems. Damage assessment data, made available by reconnaissance satellite systems over enemy installations, are relayed to command via the data processing center, which is simultaneously collating and assessing damage incurred at installations within the zone of the interior. The entire process is repeated, hopefully without undue degradation, for subsequent enemy ICBM salvos.

In summarizing this section, a number of key concepts appear to merit re-

DATA FLOW IN IDEALIZED ABM SYSTEM

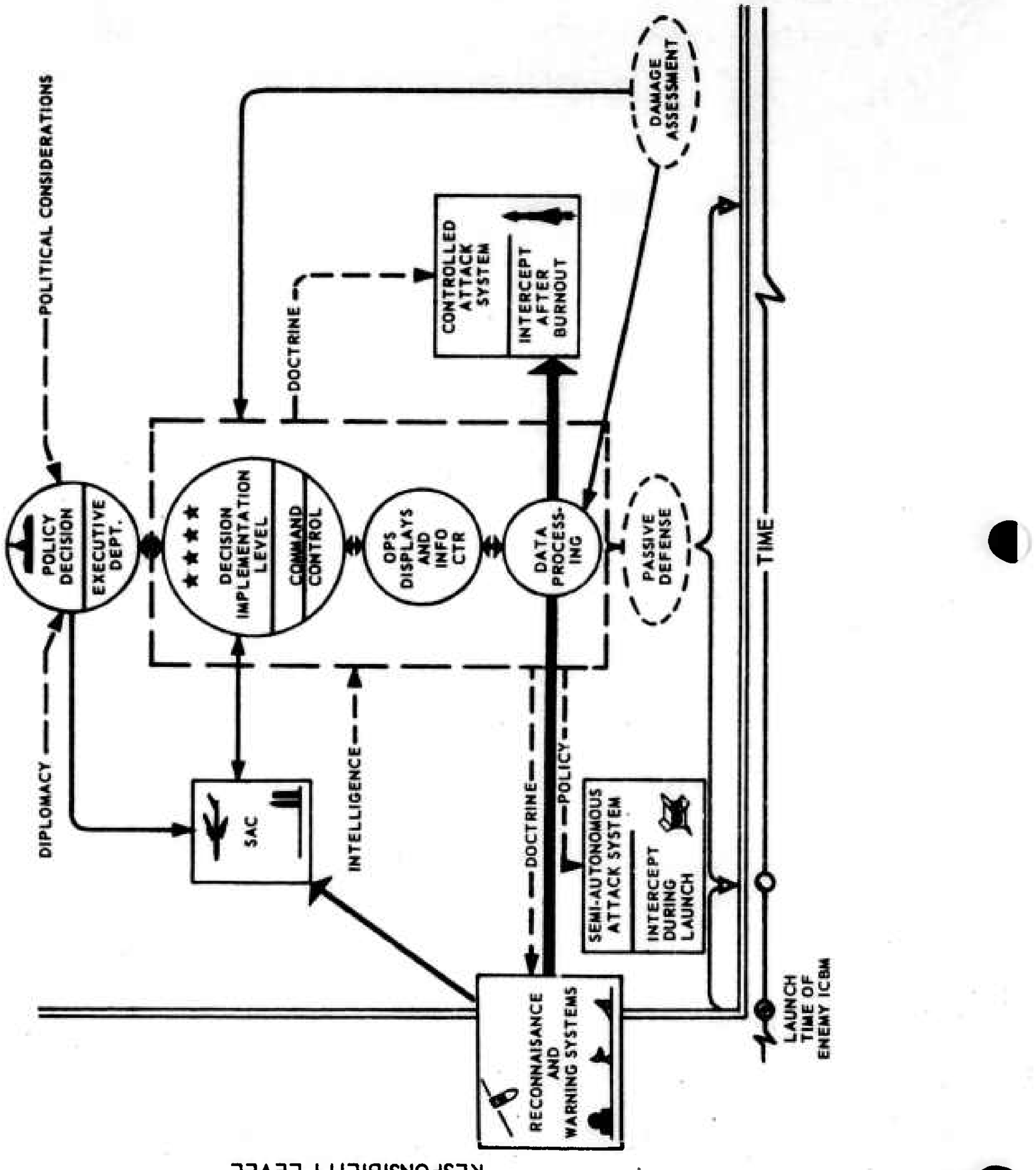

Figure 7

emphasis. As presently conceived, the actual responsibility for aerospace defense has been placed upon Commander-in-Chief, North American Air Defense (CINCNORAD). He must accomplish this mission in the best possible way with the tools (both men and machines) available to him, and within the framework of current policy decisions and the military posture based thereon. The ABM system model outlined in this section shows that CINCNORAD has four major organizational tools for accomplishing his task: a reconnaissance/warning system, an active attack system, a passive defense system, and a communications system through which he exercises command and control of all elements.

Command-control information must flow with extreme rapidity and precision between sensing and action elements to provide an effective ABM defense. Control must be maintained to allow for changes which may occur in the policy position, the operating doctrine sensitive to unprogrammed events, the nature and extent of threat, and in changes in subsystem performance due to damage or malfunction. If the commander needed only a previously made policy decision for initiation of defensive action, it is conceivable that his function might, at some future date, be largely relegated to administration, maintenance, and logistics. The logical operations stemming from a policy decision previously available could be programmed into an automatic system whose output would go directly to the defense (weapon) subsystem. However, many other factors, particularly changes in the nature of the threat and in subsystem status, will require additional decisions not programmed, and perhaps not programmable. Many of these decision will be based upon value judgements which are unsupported by quantitative information.

The mechanization of any activity at the command center, whether it be decision making, computation, intelligence analysis, pattern identification, time to initiate action, or the storage and retrieval of information, involves the union of two lines of research. These lines of research are determination of the essential logical pattern of the activity, and the discovery or invention of a mechanism which will be the physical analogue of the logical pattern.

Before concluding this summary, one final item deserves brief mention, and that is man's role in space-based systems associated with ABM defense. Although little detailed information is available at this time on the human role in space-based systems, several tentative conclusions are offered. First, developers of present-day systems and planners of near-future systems do not see any justifiable human role in military space vehicles for some time to come. Man's role will be simply as a part of ground support necessary for the checkout and launching of space vehicles.

Although some individuals are willing to discuss the possibilities of humans in space roles (such as identifying an unknown space object from space patrol vehicles or performing certain maintenance activities on our own orbiting vehicles) there is no wide-spread consideration of these possibilities by systems planners at the present time. On the other hand, it is apparent from talks with military people that they have a very open mind on the subject. Therefore, if the futuristic concepts of a growing number of serious-minded weapon system planners are assumed to be reasonably accurate predictors of systems to come, man's role takes on a new aura of importance. The human factors problems of man in space pose a whole new set of problems which need to be explored through timely research.

CHAPTER III

THE ROLE OF MAN IN A FUTURE ABM COMMAND AND CONTROL SYSTEM

Any future ABM system must be designed to provide information about, plus prediction and analysis of, very complex phenomena. In reviewing the voluminous literature on the topic and in subsequent attempts to abstract meaningful relationships from this mass of data, one factor stands out above all others, and that is the exponential expansion of these phenomena as a function of time. For example, the warhead-decoy cloud composition, its velocity, trajectory, probable impact point, as well as the number of ICBMs in salvos, etc., plus the disposition and status of defense forces, are but a few of the items to be analyzed and processed by the system. The need to obtain precise information about those elements over which the enemy exercises control, leads to the military requirement of complex information processing and control systems.

A consideration of the economic aspects of the problem, in terms of capacity of gross national product to absorb the costs of such a system, is well beyond the scope of this report. However, at national policy-planning levels this factor must be given highest priority in terms of the tradeoff between emphasis on passive (hardening, mobility, shelters) measures and active defense measures.

One of the economic factors with which this study is tangentially concerned at present, and will be more directly concerned in future efforts, is the cost in manpower to conceive of and develop, as well as to operate these supra-systems. The total manpower reservoir of the future and its growth potential in terms of the flurry of scientific and technological training programs now underway or in the planning stage will become as critical a factor in the design of future systems as is the dollar and materiel cost.

With the foregoing general comments providing a broad frame of reference within which the role of man in future systems has been examined, attention is next focused upon the principles of organization and criteria for selection between alternate organizations for command and control of ABM defense systems. (6)

One of the tutorial values of this study effort is believed to lie in furnishing guidance to military and other senior staff planning officials on the objectives, policies and tasks which define and determine the human role in future ABM systems. It will also provide indications of the planning required in meeting the critical issues of manpower and organization.

Secondly, this study may offer guidance to the military commander in comprehending certain basic implications of highly automated systems in terms of the decision-responsibility allocations which design limitations or innovations may largely determine. Within the command and control context, flexibility of organization and the potential for program substitution are basic requirements. Entirely unanticipated enemy actions, presently unknown threats, new tactics, and revised strategies, may combine or interact to pose unattainable decision-making requirements upon automatic systems designed and produced in previous years. The relatively well-known SAGE re-programming problems makes this point painfully apparent.

The designer's dilemma, which the above discussion brings to light, is enhanced not only by the lack of knowledge about the enemy and how future wars may be fought, but also by our own ignorance about the principles of systems organization and the development of criteria for making logical selections among alternate system configurations. Thus, it is essential to devise, continually re-evaluate, and to modify the programs (and/or construct systems which can be re-programmed in short order from a library of alternate programs in being), according to which automatic actions or processes are to be accomplished in future systems.[2]

The primary emphasis in this section is on the organization of command and control structures at all echelons, from subsystem to supra-system, that will permit optimum utilization of weapons and resources in meeting a defense objective. While attention will be focused, primarily, on the organization required to command system alert and to command and control the defensive force during attack, many of these principles will apply to other levels of organization or to passive defense systems.

First of all, there is an operational distinction made between the functions of command and control. To control is to operate within prescribed limits. Specification of these limits is a command function. The command function is also responsible for the establishment of organization and the degree to which the control system is activated.

The chain of command constitutes the basic organization structure for both command and control. Authority is delegated to each level, permitting action alternatives with prescribed limits. As information is passed up from lower to higher echelons it must be filtered and presented in a form which meets the requirements of individuals at succeeding levels without overloading them with display or irrelevant details. Through allocation of specified areas of responsibility in command centers, a higher echelon staff officer can, upon demand, monitor or control specific functions as required by a changing situation.

The high degree of mobility and firepower which is inherent in an ICBM attack largely determines the data rate environment within which the modern defensive system must operate. The individuals who must operate these systems have a limited capacity for data processing but excel at extracting trends and patterns buried in large masses of information. Automatic systems excel in rapid computation and precise data storage.

[2] For a comprehensive discussion of this topic, specifically related to the decision-making process, see Reference 1.

In all the quantitative aspects of a developing situation, appropriate computer facilities can outstrip the human in speed of calculation, in data retention, and in logical prognostication. Where qualitative factors are involved, or where significant and necessary data are lacking, the problem takes on a different character, in that human value judgments are required. In this case, the automatic processing and display of data can only serve as an aid to the human user in exercising his own judgment and his own discrimination.

The concentration of firepower within the active defense system tends to make the defense system itself an attractive ICBM target. Therefore, the command and control structure must be so organized that decrease in defense effectiveness caused by direct ICBM attack is commensurate with the cost of that attack to the enemy. The term graceful degradation is often applied to this concept and it also implies that allocation of function to echelons in the organization at the basic weapon subsystem should be such as to maintain the effectiveness of the defense system. Thus, the basic requirement in organization is that any damage to elements of the system, other than to the weapon and target/weapon pairing subsystems, will not eliminate completely the effectiveness of the total system.

This basic requirement leads to the argument for essentially autonomous dueling-type defense systems in which the times between detection and intercept are on the order of seconds or a few minutes at most. This latter requirement demands that extensive analyses must be made of the functions allocated to men and machines at the subsystems level. In those time-limited situations wherein extremely high data rates obtain, i.e., in the last few moments of a terminal defensive system action, and where the alternative courses of action are limited (for example, to target/weapon pairing activities of a logical nature suited to the data rate handling capabilities of a computer), there seems little question that complete automation is the answer. The appropriate place for automation is where no thinking is required. However, the requirement for human decision-making will continue to exist until that time when self-programming, heuristic automata can supplant men in selecting from alternatives which intrude themselves into the tactical or strategic situation after the action has been initiated and after the programs have been written.

In general, control functions of the near future will be limited to operation within a few sets of carefully organized procedures for which computers have been programmed and personnel trained prior to an overt act by the enemy. Until nearly instantaneous self-programming automata are available, no new procedures can be implemented after detection of a strike. For example, the weighing of the reliability and validity of the data being processed, which is a significant factor closely associated with the problems of discrimination between warheads and decoys in terminal defense weapons systems, will require automatic handling, with little chance for human intervention if weapon/target pairing times are on the order of seconds. Even the command structure is limited, in the transition and strike interval, to selection from a restricted number of predetermined response categories. On the basis of the limited amount of data which the commander can assimilate (aided by essential displays of tactical and supporting intelligence information), he must determine the military situation and select the appropriate course of action.

At each level within the command structure, from highest echelons to basic subsystem weapon or sensing elements, a delegation of authority must be made which is consistent with the military significance of alternative courses of action that can be taken by the various levels.

Command implies that there are alternative courses of action from which the optimal course for a given situation must be selected. These actions can be selected, combined and sequenced in a number of ways. The higher the echelon of command, the greater the number of alternatives available. If this is not the case, then superposition of command structure upon successively lower elements whose action alternatives are essentially identical would serve only to dilute or negate the concept of graceful degradation.

The need for preplanning at all command levels partially defines the steps required for development of data processing and display equipment for intelligent exercise of command. The results of a conference held in June 1959 on the topic of Information Requirements for the Control of Combat Forces (7), provides a meaningful frame of reference within which these requirements may be examined. The following tasks outline the work which Group IV (Visual Displays) of the Armed Forces National Research Council (NRC) Vision Committee set out to accomplish or which were initiated at this conference:

1) - determination of armed forces display requirements

2) - analysis and classification of display requirements

3) - compilation of display concepts and techniques

4) - guidance for R & D work in visual displays

5) - establishment of measurement and evaluation standards

A statement by the editors of the conference proceedings is of significance within the context of the subject study and is quoted for emphasis: ". . . .in starting out with display requirements for command decisions, we chose not only what we considered to be the most important area in visual displays, and the one needing the most attention, but also what is probably the most difficult area. The difficulty lies not so much in the visual displays themselves, as in determining the relationship between the display of information and command decision processes."

The command decision processes with which this conference was concerned were oriented toward the relationship of the system with its environment. In general, there have been but few studies of command performance requirements. Most of the studies reviewed during the course of the current program have concentrated upon the decision-making aspect of the command function. An exception to this is the work done by Human Sciences Research, Incorporated. The approach in the studies reviewed has been, in general, to examine the theoretical work dealing with mathematical and statistical decision theory, economic theory of utility or value, psychological factors influencing human decision-making under controlled laboratory conditions of simple alternative choices, and current work in the area of business and military gaming theory.

The foregoing research on human decision-making is an essential and vital activity which will ultimately contribute, not only to our basic knowledge of human behavior and how it can be integrated effectively into mechanical systems but also to the final development of self-programming, heuristic automata. Nevertheless, according to the best evidence available at present time, the transition to the latter capability will occupy the talents of a host of specialists from many disciplines for at least another decade or two.

In the meantime, there exist pressing military requirements which must be met in the near future with less than ultimate automatic devices to accomplish the defense functions which must be performed within the time period under consideration.

There exists a tendency in some quarters to think of the commander of a force as being some kind of a control element, or sort of a servo-mechanism, whose task is to sit before a display and make a series of trivial yes or no binary-type decisions. The situation is not that simple. Many of these factual, data-backed relationships can be correlated, processed, and presented in the form of sub-decisions on a computer-fed display.

At higher echelons the commander's decision is only based in part upon the immediate tactical situation. He must also estimate the subjective probability of success of the action he is about to take. The information which is presented to the commander will influence the accuracy with which he makes an estimate of the situation. His fundamental decision is related to when action should be initiated. The data upon which this decision is based may not, under many circumstances, be available for pre-programming into the system. If there are roles for man in the command of future ABM systems, certainly one of them is to recognize (what can not be pre-programmed) that we can not know in advance the precise moves the enemy will make once the action begins.

The conference mentioned previously was predicated on the assumption that a human being will have the responsibility for making important military decisions. This basic assumption was accepted by all the military representatives. However, there were differences of opinion regarding the desirable degree of automation. Irrespective of the extent of automation deemed necessary, all military representatives expressed a need for an almost exclusively visual form of data presentation.

Because of the relevancy of the Armed Forces-NRC Committee on Vision conference deliberations, as to the steps required in developing data processing and display equipment for command, a summary of the more significant issues merit inclusion in this report:

1) - The opinion was expressed that the decision-maker's primary job is the weighing of the reliability and validity of his information. If he can make this evaluation, his decision is largely predetermined.

2) - Questions arose as to the independence of the informational requirements and the method of display. The following statements of opinion were given:

a) - The primary problem has to do with what should be displayed, since the question of informational display technique is distinctly of second nature.

b) - The particular way in which essential information is encoded or displayed is not of primary importance to the kinds of decisions that are made.

c) - The significant problem is the accurate description of the mission of the control system.

d) - If other parts of the system are well conceived, the so-called display problem often practically solves itself.

e) - When determining what information is needed, is it not necessary to consider the ways in which information is displayed?

f) - The method of display and encoding is extremely important, not only to the decision one makes, but also to the amount of information that is originally required on the displays. Differences in decisions are almost completely dependent upon the way in which information is displayed.

3) - A related problem is reflected by the expressed opinion that one cannot decide what kind of display system to use until the data processing techniques have been determined.

4) - It was suggested that the commander must have independent sources of information so that he can monitor the automatic system.

5) - To what extent does the front end (sensors, etc.) of the control system, with all its inherent characteristics of selection, filtering, noise, compression, and deliberate transformation, control the decision process?

6) - The way in which command and control is exercised (centralized vs de-centralized) will greatly affect the informational and display requirements.

7) - The problem of the commander is to know what state he is in. This can be viewed as a problem in pattern perception.

8) - Questions were raised (but no conclusions reached) with regard to the concept of management or command by exception, and the kinds of decisions that would be made from such displays of exceptions rather than from basic data.

It is evident, from the controversial and often contradictory nature of the opinions expressed by the many qualified scientists who participated in the conference, that the surface of the command and control display problem has barely been scratched. However, there are a number of techniques which may be useful in solving these problems, some of which have been explored already or will be utilized in subsequent studies by this project team. They include: (1) experimental war gaming, employing computers whose output would be presented in real time in dynamic displays, (2) operations analysis relation of input to output variables based upon the assumption that if information is used, it is needed, (3) questionnaire techniques wherein commanders are queried as to what information they use in reaching their decisions, and (4) a synthesis of techniques and methods based upon the results of current and continuing research on fundamental processes contributing to the information-handling and decision-making activities of human beings.

A distinction can be made, at any level of system organization, between required outputs and required inputs. The output and input requirements largely determine system transfer functions but do not determine system configurations. The configuration, though dependent in some degree upon state-of-the-art, cost effectiveness, manpower considerations, and similar factors, may be largely determined by the nature of the threat and the military posture of the nation requiring the system.

In the case of terminal defense dueling systems which must operate within the expected ICBM induced environment of the 1965 to 1975 period, the requirement for pre-planning some rather severely limited-action alternatives essentially defines the steps required in developing data processing and display equipment for command. These steps include determination of control system needs for command action, description of the situations for which alternative procedures are appropriate, and development of a data processing and display concept that will permit the commander to assess action situations.

The sequence of operations required in developing data processing and display equipment for command of a weapon system stem from a fundamental analysis of the mission to be performed and the basic system concept which will accomplish the mission with maximum effectiveness. Within the total ABM system context, integrated unit action is a required combat function. Performance of this function gives rise to requirements for system capability to control and coordinate the action. The system capability for control and coordination is embedded in the structure of the command and communication system.

In order to provide the conceptualization for an ABM command

and control system capable of meeting the requirements of those charged with responsibility for specification of display and control design characteristics, several major classes of information are needed (8):

a) - The terms describing unit performance of ABM defense systems must be operationally defined in quantitative, **measurable terms**.

b) - The men and machines which constitute the weapon system must be described along the set of dimensions relevant to mission performance.

c) - The effect of the external environment on the weapon system must be determined for both man-machine components and, subsequently, on system performance.

With the formulation outlined above, the weapon systems planner is in a position to make realistic tradeoffs among his resources to achieve desired system performance characteristics under both combat and traffic phases of the system mission. This formulation includes the explicit assumption of combat phases involving action and counteraction against a purposeful opponent with a full awareness by the system planners that all possible tactical circumstances cannot be foreseen and pre-programmed. Combat phases are characterized by a two-sided action in which the ABM system and the ICBM are antagonists dueling in a common environment. Thus, the determination of requirements information for ABM defense system must take into account the two-sided characteristics of the tactical environment within which its mission is carried out.

As was stated in previous sections of this report, one of the primary tasks undertaken by the project team was that of developing a frame of reference within which studies conducted by Bell Telephone Laboratories on communication requirements, and those conducted by Stanford Research Institute on tactical employment and deployment of ABM systems, could be reconciled with the role to be played by human components of the system. The Bell studies have produced a number of criteria and requirements which must be met in establishing the command and control structure configuration, the following summary of which is abstracted from a discussion of the terminal defense system concept. From an examination of other defense system concepts, it appears that these criteria and requirements are generally applicable to all ABM systems (6).

a) - The system must have the basic capability to employ weapons when they are isolated from higher echelons of command and control.

b) - The higher echelons of command and control should be such as to increase the defense effectiveness above that of basic capability.

c) - The responsibility of an officer, in terms of the results of an error in decision, should be commensurate with his rank. Centralization of portions of command and control will, in part, stem from this requirement.

d) - The capability of a human to assimilate data and reach a decision should not be exceeded.

e) - After the preceding requirements are met, system costs should be minimized.

To meet the basic capability requirement, control functions (surveillance, identification, tactical control, and guidance) in defensive weapon systems should be established at the detection, weapon-launcher level.

Centralization of surveillance and identification may make the system more efficient, but basic capability must remain at the weapon. Centralization of a monitor-and-veto tactical control function may permit a senior commander to increase the effectiveness of the defense by extending the classes of target that can be attacked beyond that available to the basic capability functions of the weapons.

As we review information which is available in the open literature on the proposed role of NORAD in the aerospace defense mission, we are impressed with and alarmed by the apparent tendency to route vast amounts of raw or only partially-filtered data into one centralized data processing center. According to these publicized plans, NORAD will ultimately exercise control over SPASUR, Space Track, The National Space Surveillance Center, BMEWS, Nike-Zeus, Anti-Satellite Satellites, Anti-Satellite Missiles, Space Based ABM Systems, MIDAS, SAMOS, and conceivably, other systems still farther downstream.

Again we cite the conclusions reached by the Bell Telephone Laboratory group involved in this problem: "It is clear," they state, "that there are masses of controlled, system-derived data that could be made available to a commander or controller. However, because of his limited capacity (and that of automatic processing systems of the near future), the organization of the data processing in the command and control structures must be such as to capitalize on the commander's ability, but not to overburden him."

"Within the chain of command, specific delegations are made at each level. As a decision is referred to a higher echelon, data pertinent to that decision must be transmitted. Since a higher level commander has several branches to the next lower level, but a limited capacity, the system must be such as to present him, along each branch, with less detailed data, than is available at the lower level." (6)

There are at least three methods available for accomplishing this data reduction. The first method, delegation of authority, suggests that the commander does not require the data on the situation pertinent to decisions within the delegation.

A second method of limiting the amount of information presented to higher levels is to transmit a summary of the data. The precision in any raw data transmitted is reduced, or the information is encoded in a different form, the objective being to make the total amount of information constant at each echelon. The significance of the information may increase, at higher levels, the degree commensurate with the level of responsibility.

A third information-limiting method for display to an individual commander is to modify the organization to include staff positions whose function is to keep an up-to-date picture of the situation relevant to specific areas of responsibility. As long as the action remains within specified limits, no further attention is required. If the action gets out of prescribed bounds, the commander can then devote full attention to it.

The Bell study also recognizes that certain constraints are placed upon the organization for command and for control of a weapon system. These boundary conditions are: (a) firepower, (b) mobility, (c) system data processing capability, and (d) the capability of the human components in the system. These constraints result in certain implications for the command function and for the organization of command and control structures, both by function and by relative position of subsystems. The implications of these boundary conditions are on the physical organization of the command and control subsystems, and on their operational employment. The physical deployment of the defense subsystem must be such that it forces the enemy to pay the highest possible price to accomplish his objective. If system design is proper, the degree to which effectiveness is decreased is directly proportionate to the force an attacker must devote to the decrease.

The combination of limitations of components, plus mobility of an attacker, lead to the requirement for detailed planning of both command and control prior to actual combat. In the actual combat situation, subsystem action responses are limited to selection among a few alternatives and operation within a few sets of rules. However, such a restriction does not lead to inflexibility, according to the Bell reports, nor to a completely automated system.

The apparent move, mentioned earlier, to place the responsibility for all aerospace defense activities under one central command, is probably justified on the basis that effective, coordinated action must stem from one central authority possessing the requisite information necessary to act within the time-compressed environment of the future. Conversely, unless the subsystems which make up the NORAD supra-defense system have the capability for independent action and some residual means for communicating with other independent systems, the concept of graceful degradation is grossly violated.

With this factor in mind, it has been generally agreed upon by responsible systems planners and military authorities that the alert level is established by the highest command echelon in the defense structure.

However, there are two main exceptions to this rule, i.e., (1) general release of nuclear weapons is the prerogative of the executive department (the President, or his delegate), (2) local release of weapons in the event of (known) hostile acts and disruption of communications may be the prerogative of the lowest level commander. Within this context, it appears that three levels of combat command are appropriate:

1) - There should be a commander at the basic weapon or sensing element to direct it to adopt basic capability procedures when isolated from higher command.

2) - At the levels of subsystems (weapons or sensing elements) with overlapping coverage, there should be a commander presented with the tactical picture so that he is enabled to direct changes in operating procedures and organization consistent with the condition of attack and defense.

3) - At the level of defense of the United States (NORAD), there should be a commander empowered to command changes in operating procedures from changes in defense objective.

At every command echelon, the combined effects of improved defense weapon system capability and the high degree of mobility and firepower possessed by the attacker will require the commander to assess a tactical situation of greater scope than ever before. He will be required to make more and finer discriminations about the situation and may be presented with a wider range of action alternatives than those built into current weapon systems. The commander of future ABM systems will need advanced control and communication systems in order to permit accurate and timely implementation of the coordinated action required to carry out his decisions within the compressed time intervals characterizing the environment in which these systems will operate.

Fundamentally, the techniques employed in extrapolation to future systems are not the same as those utilized in studying present systems. An attempt must be made to ascertain trends in terms of projected state-of-the-art developments as well as estimated enemy capabilities and potential. New tactics and procedures must be developed by which future man-machine systems can be most efficiently employed. However, unless we are guided by an appropriate statement of assumptions which establishes a context for a statement of requirements, the whole process becomes a sterile exercise. For any weapon system these assumptions must include a definition of the system mission, and an estimation of system capability under the environmental conditions, both natural and enemy-induced, within which it is expected to operate.

The translation of future ABM system requirements (specifically, those requirements which will be levied upon its human components) into a design guide for system planners, constitutes one of the major objectives of a large portion of the research effort reviewed during the current study. In addition to all the other material reviewed, well over fifty separate reports, each concerned with the specific problem of human engineering analysis, procedures, and methods, were analyzed for the purpose of obtaining an insight into the current status of research methodology as it applies to weapon system requirement-setting studies.

Special mention should be made of an outstanding series of studies which have been completed on the quantification of requirements information by the staff of Human Sciences Research, Incorporated, of Arlington, Virginia. These studies, about fifteen to date, constitute a number of unique advances in approach and technique which, if implemented, will provide much of the basis for the development and quantification of human factors requirements in future ABM systems. One of the latest studies by the Human Sciences Research, Incorporated, which deserves special mention, identifies some of the factors to be considered when attempting to project United States weapon system capabilities and those of the enemy. An operational gaming approach to quantification of information requirements is described. The framework is laid for future detailed synthesis of the command information and control requirements for the advanced submarine in an anti-submarine warfare mission (5, 9).

The study programs noted above, plus several equally sophisticated efforts by other organizations, have provided a useful frame of reference from which the Convair task group can proceed to develop, in subsequent programs, a human factors design guide for the planners of future ABM systems.

One of the objectives of this study, mentioned previously in Chapter I, was to develop an outline for a design guide dealing specifically with the human element of future ABM systems. Chapter V will present this outline in some detail and will attempt to set forth the methods and procedures that would be useful to both industry and procuring agencies in developing and producing new ABM systems.

In summarizing this section, we should again point to the complex nature of the problem. Whether one is dealing with interacting systems of computers at NORAD for processing masses of data supplied by subsystem activities, or dealing with simple verbal messages being passed between individuals, it is necessary to first recognize what information is important to the successful conduct of system mission, what is redundant and should be filtered out of the system, and what information should be stored for future reference. It is neither meaningful nor profitable to develop or construct elaborate machinery to process or display information per se. Before the system designer can develop programs for data processing systems and display devices, he must know what to program, or as an alternative, develop self-programming systems. Until future technical advances come up with heuristic systems, the programmer must know in specific detail precisely what action alternatives must be incorporated in the system. A mere list of information requirements, no matter how sophisticated, is a necessary but not a sufficient condition. A more fundamental question relates to what the man-machine system is to do with the required information.

Another important factor, usually overlooked, or perhaps considered beyond the scope of a study on the subject of the human role in advanced systems, is that of the problem faced by military planners in manning the command echelons of these systems. As indicated previously, the personnel subsystem requirements area has received more research emphasis than other types of system requirements. However, these requirements have largely been focused upon operator and maintenance performance with relatively little effort on the establishment of command performance requirements.

CHAPTER IV

PERSONNEL SUBSYSTEM DEVELOPMENT PROGRAM

One aspect of the human factors problem which has become more and more apparent in the course of this study is the importance of the human role in management of system development programs. In fact, since this aspect of defense may be the most critical one of the future, a brief discussion of it is necessary. In addition, the development of a systems guide, which is outlined in Chapter V, is also directed toward systems managers. It is unfortunately true that there are few, if any, systems development teams that are trained for the difficult job which faces them. There is far too little use or even understanding of the scientific approach in solving what is probably the most important job facing us today, which is the development of an integrated defense system. The diagram shown in Figure 8 depicts one way of defining the elements of this human factors problem. In it we note that the elements on the left characterize the military role while those on the right refer to industry. We have made this division, assuming that the military is really the ultimate manager, whereas industry assumes, primarily, the role of producer. As manager the military must have a set of procedures by which it can carry out this function. These procedures will be carried out by people which makes this a fundamental human factors problem in itself. Likewise, industry must have an organization for managing their part of the problem. The management problems on both sides of the picture are extremely complex and create a challenge to serious-minded researchers, because these management efforts have the power to create, or fail to create, an effective defense system.

The defense system industrial and military team must be trained in the use of the scientific approach. We can no longer afford the costly luxury of cut-and-try or on-the-job training. Membership on the management team must not be by election or seniority only.

ELEMENTS OF THE HUMAN FACTORS PROBLEM

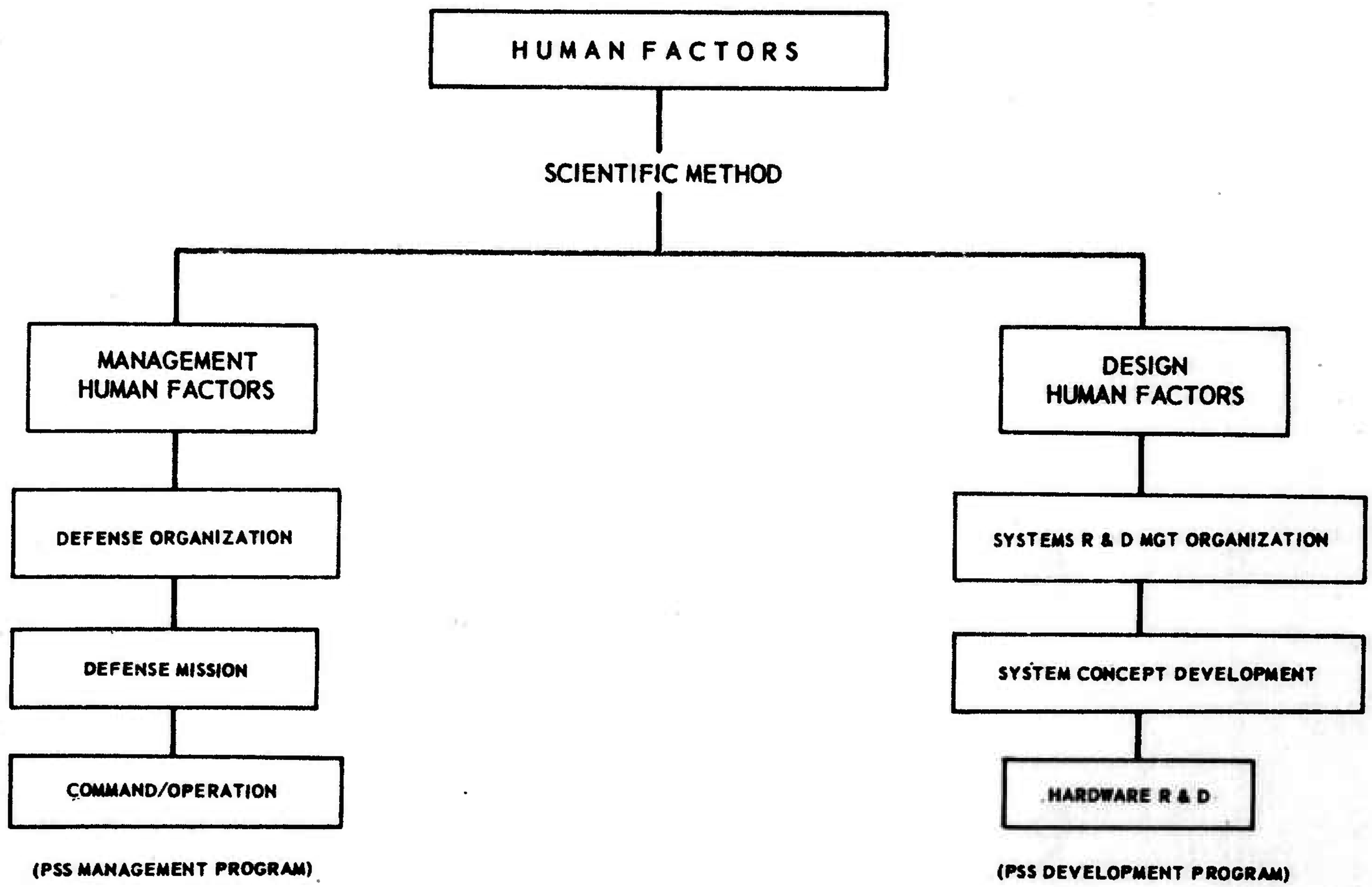

Figure 8

Referring to the second element on the chart we indicate the next critical area which also needs the benefit of the scientific approach. When the systems concepts are developed, it takes another team, not a group of isolated experts who attempt to argue their compromises out around a conference table. How do we select and train teams in the military establishment and in industry? Can we afford to rely solely on the judgment and experience of a good project manager? Good managers are hard to find, and even when we find one it is doubtful whether he has paid sufficient attention to the need for training his project team, or whether he would really know how.

When considering future systems it is painfully apparent that past experience and past training exercises can be truly deficient in coping with advanced system requirements. It is a common fault found in most systems development programs that old ideas, often old mistakes, are used instead of good creative scientific thinking. Many cases can be cited where the same human engineering deficiencies are perpetuated from one system to another, year after year. Discussions with many groups during this study provide convincing evidence that this perpetuation of errors happens because no one seems to have time to look at the cause, which is really a human factor problem. Many people are managing and creating these systems. These people are not individually at fault, but they are collectively at fault because of lack of organization and training as a team.

The recent push by the Air Force to develop a personnel subsystem management concept may be the first step in bringing to the attention of cognizant authority the dire need for better management of systems development. The success of this program is still dependent, however, upon people, their skills, experience, training and motivation. A further step is needed to assure success of the program, i.e., a trained team. It is not within the scope of this study to say how this should be accomplished but it is important to identify the need for a system development team training program and it is suggested that studies be initiated to determine when and how to train such teams, and who should do it. We can no longer afford to decide the course of a systems development program without application of the scientific approach to its management.

In general, military policies and concepts for weapon systems management are detailed in the various regulatory documents promulgated by the separate services. These concepts recognize and emphasize the growing importance of early (up to ten years in advance) consideration and determination of man's capability, limitations, availability, and role in the highly technical and complex systems of the future. These considerations, if implemented at highest echelons in both industry and the military, will lead to realistic manpower programming of quantities and qualities of skills which are compatible with the national manpower resources, and with the lead times necessary for recruitment, training, and placement of the right skills in proper numbers in the right place and at the right time. These considerations may also suggest or dictate system and hardware design changes during the conceptual phase, thus insuring that the system meets man's needs and is compatible with his abilities and limitations.

Human factors programs range from selection and training of personnel, to the design and modification of machine portions of a system. In general, the more attention paid to the human factors consequences of machine design, the less severe are the requirements for personnel selection and training. Consequently, the process of identifying and training human beings cannot be divorced from the problem of designing equipment so that it is compatible with the capabilities and limitations of these human beings; nor can it be separated from the problem of preparing training aids which can be used and understood by these human beings (10).

Within the Air Force, specifically in the Air Research and Development Command (ARDC), the System Project Office (SPO) management procedures are being established to expedite and tie together the total weapon system development program. In the development of personnel and training support, the SPO is primarily concerned with the integration and time-phasing of actions, while the Air Training Command (ATC) and using command are responsible for preparation and implementation of weapon system training.

Recent policy agreements reached between various echelons in the Air Force are designed to insure that respective command functional responsibilities are exercised in the development of personnel subsystems. A program is now under way within the Air Force, and hopefully, in the other armed services, to spell out these requirements in detail and to incorporate them into regulations governing the development and procurement of future weapon systems, with appropriate and timely emphasis on personnel subsystems.

The personnel subsystem, according to Air Force definition, is a composite of the trained military personnel and employment techniques required to operate, control, and maintain the integrated hardware subsystems of the weapon system. The major elements required in the development of the personnel subsystem are:

1) - Personnel - Equipment Data (PED)

PED is a centrally-maintained (contractor and military laboratory-generated) body of analytical data, in the form of task and equipment information, that defines the interrelationship of functions performed by system people and system hardware.

2) - Human Engineering (HE)

HE is the application of basic knowledge of man's unique capabilities and limitations to equipment design.

3) - Qualitative Personnel Requirements Information (QPRI)

QPRI is planning information that identifies all duty positions that are required to operate, maintain, and control a weapon system. This information will be published in a QPRI report that includes estimated manning requirements and recommendations for and descriptions of Air Force specialists in all identified positions.

4) - Training Concept (TC)

The TC (based on PED, QPRI, preliminary operational plans, logistic concepts, development plans and current training programs) indicates how the skills, knowledges and abilities will be acquired by all people who will man the system.

5) - Training Equipment Planning Information (TEPI)

TEPI is planning information that presents the contractor's recommendations on training equipment (simulators, mobile training units, devices and parts) considered necessary to support system training.

6) - Training Equipment Development (TED)

TED includes the establishment of requirements and procurement (with design and development as necessary) of all equipment needed by the using and supporting commands for training.

7) - Training Plans

Training plans, expanding the elements contained in the TC and based on approved operational, logistics and maintenance plans, QPRI, TEPI and training requirements, are detailed definitions of methods to be employed and support required to accomplish individual training (test), individual training (operational), and crew and unit training (test and operational).

8) - Technical Orders and Technical Manuals (TOTM)

The technical manuals contain instructions and information designed to support appropriate training courses, as well as job performance of Air Force personnel engaged in operation, maintenance, service, overhaul, installation, and inspection of specific items of service-test, in-production, and in-service weapon systems and weapon systems support equipment.

9) - Personnel Subsystem Test and Evaluation

Air Force regulations define the program called for in this item as Categories I and II Testing. Functionally equivalent test programs are called for by other military services. Category I consists of development testing of individual components and subsystems of a system. Category II consists of development testing and evaluation of integrated systems through the mating process that progresses into a complete system.

A recent WADD report, which concerns the problems associated with the testing of man-machine components in current ballistic missile systems, contained some rather discouraging comments on the adequacy and completeness of human engineering testing and malfunction data collection activities.

In summarizing their findings, the authors of the WADD report make the following pertinent comments, "....an examination of the practices followed in nine Air Force missile system test programs for obtaining performance and malfunction data concerning system human components leads to the following conclusions: (1) little, if any, systematic human factors performance testing is being undertaken, (2) the malfunction data collection systems being used are inadequate for identifying or obtaining pertinent data on human-initiated malfunctions." (11)

Within the military organizations, procedures have been set forth in a number of regulatory documents spelling out, in detail, the testing and evaluation programs required under the personnel subsystems management concept. However, until the impact of this concept has been felt at all echelons of command, and until this need for integrating man into the weapon system at the initial planning stages is translated into workable and practical techniques about which there is a meeting of the minds between those who require the weapon systems and those who build them, little will be accomplished to materially improve weapon system effectiveness in terms of its human components.

Into the predictable future, as attested by the findings of many recent writings and conferences on the topic of man's function in command and control, man will play an ever-increasingly responsible role in the ultimate commitment of a weapon system to action. As we have heard emphasized so often by well-informed military officials and systems planners, the system is for man's use and man's protection. It is because of this that we would like to suggest ways and means of assisting military planners in the task of integrating the personnel subsystem program into the overall weapon system.

In considering the overall picture, a number of critical factors are examined in the light of their functional relationships. These factors require extended examination prior to resolution of other, more detailed considerations. These factors include:

1) - The need for more emphasis on detailed, initial planning related to the integration of a specific weapon system into the supra-system in terms of the manpower/economic/technical resources of the country.

2) - The complexity of organizational structure and regulatory documents within both industry and in the military organizations which often serves to constrain the effective development, interpretation, and dissemination of command level requirements information to all project management echelons.

3) - The interface relationship between the military organizations and industry, at all levels, pertinent to dissemination of requirements information to all project management echelons.

4) - An understanding and firm conviction that requirements are not static, but that they originate within a dynamic, changing frame of reference in which the military retains prime responsibility while

simultaneously integrating inputs from industry for most effective system development.

It is apparent from present service efforts to establish a policy and regulations related thereto which will govern each and every echelon of the military management structure, that it will be necessary for industry to develop techniques whereby these policies and regulations can be reconciled through an interface adjustment mechanism. It is believed that a concerted study effort devoted to this problem area would provide guide lines from which both the military and industry could improve contractor-customer interaction for integrating many factors affecting the management of weapons system development programs.

For many years industry has traditionally expected the military to generate command and control requirements. There are many instances, however, where the armed services have pointed out that these requirements are conceived as the direct result of new technical concepts or state-of-the-art hardware advances which emanate from industry. This activity often degenerates into a hit-or-miss process which could be improved by better communications between producer and user. How to improve or expand the necessary communications channels between producer and user should be given serious attention. This factor is important to the military organizations in getting what they need and to the contractor in helping him meet these needs.

The very complexity of future ABM systems dictates that the United States can no longer afford the luxury of piecemeal integration of the various supporting subsystems into the supra-system. The system, including its human components, especially at the command level, must be operational as a whole at a specified date, or it will not meet the military requirement for an effective ABM system.

CHAPTER V

SYSTEMS DESIGN GUIDE FOR THE INTEGRATION OF MAN AND MACHINE IN ABM SYSTEM DEVELOPMENT

The guide for systems planners is intended for application to all stages of a weapon system development program. These stages include analyses, synthesis, planning, and evaluation and management control, with special emphasis on personnel subsystems development. Unlike previous handbooks which deal essentially with hardware and principles of human engineering, this document will emphasize the solution of systems integration problems facing planning agencies, project offices, and technical groups responsible for carrying out a systematic, time-phased program.

During the period of the current study, an extensive file of material has been acquired on methodology, procedures, systems models, requirement setting studies, etc., which deals with various elements of the overall system development problem. For example, these studies explored the application of system synthesis and analytic tools to such sub-areas as man-computer interaction, human engineering analysis, display-control requirements, human decision making, the human factors aspects of maintainability and reliability, and performance prediction. Certain similarities among these various approaches suggest generalizations which can be applied in a broader sense, as well as indications of limitations which require sophisticated pairing of a given technique with a specific aspect of man-machine system development.

It will be necessary during development of the proposed guide to exercise caution in selecting only those methods and techniques which will provide quantitative results, subject to verification through objective evaluation procedures. The danger always exists that the enthusiasm generated by rigorous mathematical treatment in analytical model developments will blind the user to the departure from reality which may stem from inadequacies in the quantitative data available at early planning stages.

However, system models as analytical tools do provide great promise for analysis of total weapon systems and a sign of maturity in the field of man-machine systems analysis will be in the continuing development of useful models. A search of technical literature, and visits to various establishments with weapon system development responsibilities, indicates that considerable progress has been made recently in the development of research methodology applicable to requirement-setting studies, in specific human engineering design techniques, in optimizing man-computer relationships, in model building, in correlating system inputs with system outputs, and in the quantification of requirements information relative to these inputs and outputs.

Additional promise for the development of a utilitarian guide for systems planners is also evidenced by recent advances which have occurred in the basic science. For example, much progress is being made toward an understanding of the fundamental processes in human decision-making and these efforts may, in turn, lead to the ultimate development of heuristic, self-programming computers. Concurrent, theoretically-oriented studies are being devoted to developments in non-numeric logic systems which may lead to truly self-adaptive automata capable of learning by processes analogous to the ways in which humans vary their behavior in response to perceived changes in the environment.

On the management side, the increasing emphasis placed on the total weapon system concept by the military organizations, along with new regulatory documents being promulgated at an ever increasing rate on this subject, provides additional impetus for the creation of a guide for design which emphasizes the human element as an integral portion of the system.

The proposed approach to development of a systems design guide for the integration of man and machine in future ABM system programs is outlined in this section of the report. According to previous contractual agreements, a more detailed and explicit formulation of the outline, along with a synopsis of specific topical headings, has been submitted to the ONR contract monitor under separate cover as a special requirement in this study program.

DESIGN GUIDE OUTLINE

Introduction

1) - time phasing

2) - applicable methodologies

Mission of Defense System

Military - Industry Team Integration

System Requirement Phase

1) - research program

2) - requirement-setting studies

3) - task equipment analysis

4) - personnel subsystem planning

5) - human engineering research and development

Development and Production Phase

1) - personnel subsystems development

2) - preliminary design support

3) - human engineering evaluation

4) - mockup evaluation

5) - component and subsystems testing

Systems Test and Evaluation

1) - personnel subsystems testing

2) - malfunction data collection

3) - human engineering design modifications

4) - followup programs

The finished version of this guide will expand, in detail, on the chart shown in Figure 9 and will provide techniques and methods which will insure orderly integration of all the factors which must be considered in the development, production, and evaluation of a complete man-machine system.

MAN-MACHINE SYSTEM DEVELOPMENT

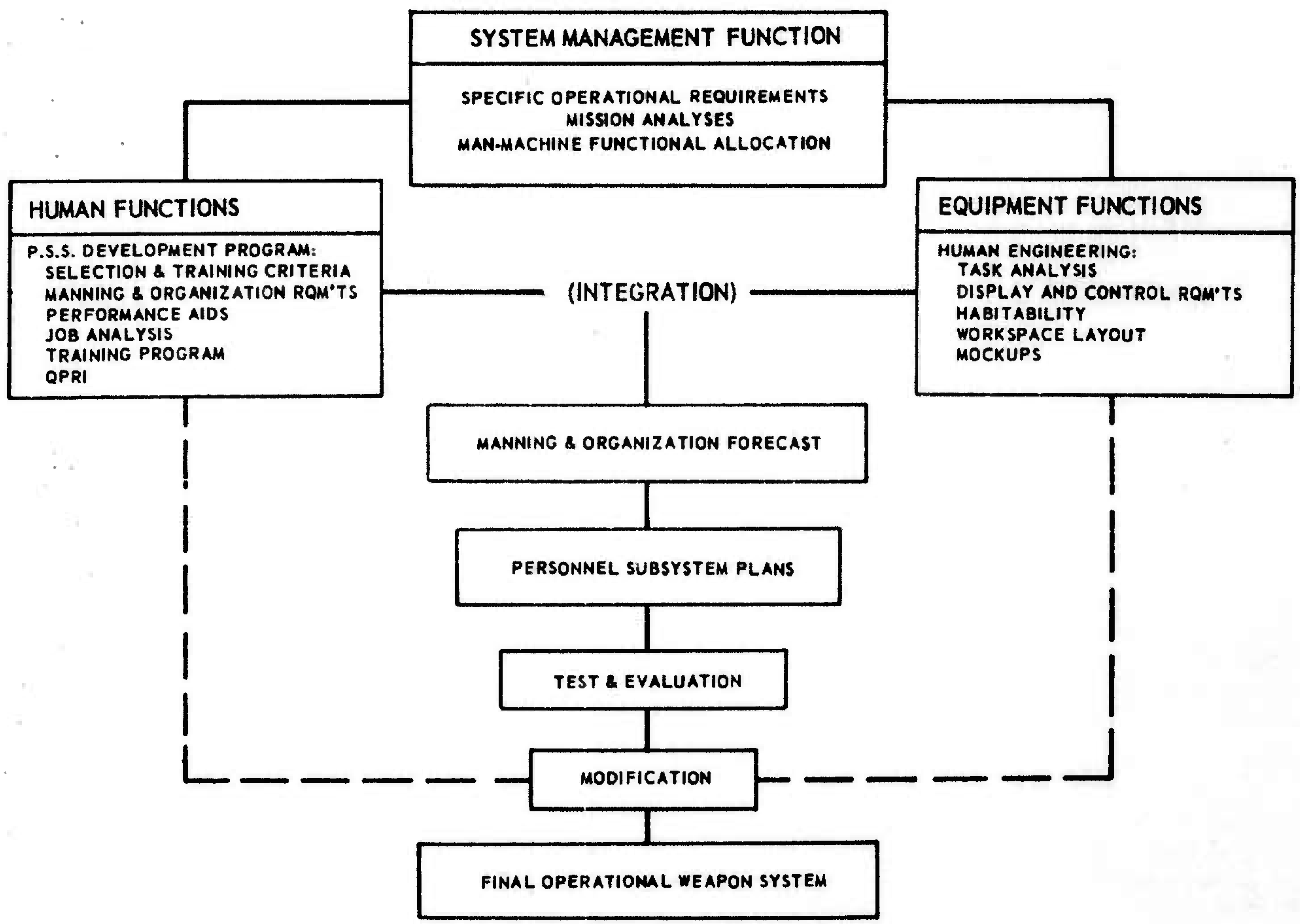

Figure 9

CHAPTER VI

ABM MAINTAINABILITY

Maintenance has been recognized as both a major cost and technological problem in all modern complex systems. The cost for maintaining a system can exceed the original cost of a system many times. During this study it has become obvious that systems designed for defense against ballistic missiles are particularly sensitive to maintenance because of their requirement for readiness within severely limited reaction times. It is the purpose of this section to define the critical maintenance problems noted during the study and to discuss each problem in relation to future design requirements.

It was found during the study that the ABM systems under development had been conceived at the beginning of the new automatic check-out concept. This, coupled with the recent accelerated activity in industry in the areas of reliability and value control, makes present ABM systems an ideal guinea pig for testing or evaluating these concepts.

It was particularly interesting to note a significant increase in numbers of personnel appearing in manning charts. An attempt was made to explore this phenomenal growth and determine what could cause such an increase in spite of concentrated endeavors to reduce the requirement for people. One of the obvious conclusions that could be reached from a purely logical point of view was that these new systems were merely larger and more complex. Why should complexity or increased numbers of units (which presumably require no assist from humans) spawn people? Unfortunately, development of personnel and training requirements is just in the beginning stages for the systems studied, so our investigation was limited primarily to eliciting opinions from various individuals who were either on the edge of this particular problem area or who had not become deeply enough involved with the problem to have formulated clear concepts of what was going to happen. The several tables of organizations reviewed are confounded by governmental organization constraints. For instance, a typical missile battery table of organization would be taken as the model for developing manning requirements. The standard complement was taken almost as it stood, with modifications reflecting only the differences which might be anticipated in the new job. It became apparent that the age-old behavior of the armed services was occurring, i.e., don't get rid of anything, just add more for the new requirement. The effect of automaticity was certainly not being reflected in these plans.

Contract personnel visited the Combat Development Department and the Human Research Unit of the U.S. Army Air Defense Center, Fort Bliss, Texas, and other installations where work is being done on human factors, human engineering, and operator and maintenance training for present and future defense systems. Several long discussions with human factors specialists working on current projects did shed some light on the automaticity/personnel question indirectly. This was evidenced in subtle maintenance philosophy shifts, where original concepts of centralized monitoring were being modified in favor of decentralized, on-the-spot repair concepts. There were cases where a plan for maintenance at a master console back at control headquarters had given way to roving or strategically-located mobile maintenance vans. The thought was frequently expressed that having a man on the spot, with his ability to see and recognize degrading conditions which were just beginning, was less expensive than trying to insert many extra sensing devices and the necessary ground communications to bring this information back to a central point. The added reliability burden was cited as an important deterrent.

Another significant factor peculiar to the ABM defense system is the problem of not being able to test complete operation of the system. With aircraft, for example, the system can be flown through a mission which serves as a total systems test. With ABM defense, however, the missile can not be routinely fired to test the total system. Naturally, parts of the system can and will be exercised, but even this will be abbreviated since these systems must be available for many years, and every time any part of the system is used for test the life expectancy is potentially reduced. This seemed to point up the value of a man who, through observation, would pick up impending failures difficult to sense automatically.

In all of these discussions it was emphasized that reliability was a prime factor in the maintenance picture and it was expected that skill-level requirements would be minimized. Nevertheless, there is considerable evidence to show that higher skill levels (although a fewer number per element) may be required in more sophisticated automatic maintenance systems. These are knotty problems facing designers of present systems and should by all means be solved before we can truly define the maintenance philosophy of any future system.

One of the obvious factors in maintenance agreed upon by everyone interviewed was that humans will probably be taking boxes out and replacing them in any system for a long time to come. No one was willing to let the machine do this task. It was also pointed out that this influenced their decision to put the maintenance crew close to the hardware. It was reasoned that the human could be useful and less expensive doing several additional tasks, since he had to be there anyway to take the box out.

As can be seen by the discussion so far, there is very little information which leads to an answer of the original question of number of people vs automaticity. Conceivably, this may be answered in time as present systems become operational and a training program is tried and evaluated. Certainly we have very little basis now upon which to justify an increase in manning as systems become automatized. Theoretically, it should be reduced. It is suggested that a very great current need is the development of a method for systems designers to assess the tradeoffs between automatic, semi-automatic, and manual maintenance.

Operational gaming may provide such a method. Operational gaming, or simulation, is a technique for obtaining quantitative predictions of the relative frequencies of the various outcomes of a multi-stage process in which the outcome of each stage in the process is subject to statistical variation. The distribution of the outcomes at each stage is estimated and the process is run through repeated trials on paper (or in a computer) in which the outcome at each stage is drawn at random from the assumed distribution. After many trials the distribution of the final result of the process may be plotted as a histogram, often with sufficient accuracy for the purpose. The process avoids such difficult mathematical calculations as convolution and Fourier transformation, which are the standard tools used for dealing with the combination of distributions. It pays for simplicity with the necessity for repeating the simulation with every change in conditions.

The technique seems to be well adapted for the study of maintenance, in which such variables as waiting time for maintenance men of the required specialties, waiting time for facilities, test equipment and parts, and other factors all contribute to the down time. The effect of such factors as manning level, stock level, reorder policy, quantity of test equipment and supplies, and methods of management, may be evaluated by simulation in a way that produces results that are difficult to come by in any other way in such a complex situation. Also, simulation lends itself to observation and criticism of a process by management people, who can thus contribute, by virtue of a wealth of practical experience, to the improvement of the process in a way that would be difficult, if not impossible, if analytic techniques were used.

Unfortunately, during this study little equipment was available for observing what is being done to improve maintainability. This is, in the final analysis, the critical deficiency area in past products. Human engineering principles have been forgotten, twisted and rationalized out of too many products, especially where maintenance is concerned. A personal visit to the DEW line by one of the principle investigators provided first-hand opportunity to observe certain types of maintenance activities that may have a bearing on future systems. The mission of the DEW line, as an early warning system, relies entirely on the effectiveness of its maintenance. The system mission cannot afford any lapse in alerting capability due to breakdown of equipment. Although redundancy is the cardinal feature which provides for this readiness status, it is also evident that the constant exercising and concomitant inspection procedures provide a means for keeping failures low and repair current. The automatic ABM system may not be blessed with this capability.

Since much of the discussion so far is based on the opinion of persons interviewed, widely variant points of view are to be expected. One school of thought condemns the emphasis on making things easy to maintain, stating that if you build it to be taken apart easily, someone will take it apart, and thereby will reduce its reliability. The other school of thought suggests that this attitude is a rationalization, and is sheer hedging against accepting the responsibility for good design. Throughout the study there was considerable evidence that maintenance activity is restrained by the philosophy that it costs too much in terms of design time to control a development program so that those ease-of-maintenance features are incorporated faithfully. There never seems to be enough time to do it correctly the first time, but always enough time to do it over.

One other factor stands out in reviewing maintainability programs, namely, that electronics maintenance has received considerably more attention than mechanical, hydraulic, pneumatic, et cetera. A number of useful guides and check lists are now available for electronics, and are being used. It is hoped that these guides will become part of future programs. There is a great need, however, for expanding these guides. Although there are many complaints about the inadequacies of such guides, it was noted that where they are being used one finds a product which reflects their use in more effective maintenance and less modification or redesign.

W. B. Knowles in a recent study of missile ground support personnel requirements surveyed the maintenance system concepts of several contemporary Air Force missile systems (12). It is perhaps significant to note one of his first observations, i.e., "It became apparent that so-called automatic electronic ground support equipment was not leading to reduced personnel requirements as had often been claimed." He further noted that with automatically selected targets, self-contained guidance, predetermined trajectories, remote command headquarters, etc., very few, if any tactical or strategic decision functions are carried on at the missile site. In a sense, the site, its equipment, personnel and operation exist primarily to maintain the weapons which are actually employed by another agency.

A maintenance system is generally thought to contain four basic functions:

a) - sampling - procedures involved in extracting information (e.g., measurement), transducing the information, and presenting it in usable form

b) - comparison - process of checking the sampled information against predetermined standards

c) - interpretation - results of the comparison are translated in terms of what must be done next

d) - action - carrying out the procedures dictated by the interpretation

The functions of sampling, comparing, and interpreting are usually combined as a test, so it is possible to consider a maintenance system as a sequence of tests and actions. When a system checks out with no adjustment or repair it can be diagrammed as a straight-through sequence, i.e.,

T1
↓
T2
↓
T3
↓
Tn
↓
Ready or Fire

These confidence checks form the trunk of what may be referred to as a testing tree. If no-go's are encountered, the trouble must be located and repaired or adjusted before the confidence testing can proceed, i.e.,

$$
\begin{tikzcd}
T1 \arrow[d] \\
T2 \arrow[d] \\
\text{(no-go)} \arrow[r] & Ta & Tb & Tc\ldots & T3 \arrow[dllll, to path={|- (\tikztotarget)}] \\
T3 \arrow[d, dashed] \\
Tn
\end{tikzcd}
$$

Here the testing branches out into the trouble-shooting sequence. For most missile systems the trunk, or confidence checks, can be programmed automatically, whereas the branch or trouble-shooting tests are still left to manual check-through by the technician. The biggest gains in lowering personnel requirements will be realized when more attention is paid to design of the technician's program. In the past tests have been automated where it was easy and well within the state-of-the-hardware-art and relegated to manual activity when readily available automatic design did not present itself. Tape or card-programmed testers offer advantages for organization level use since they can be readily adapted to prime equipment changes and can reduce the number of testers. These would be made up of fairly standard building blocks which could reduce the task of the test equipment technician.

Two other areas of the maintenance problem investigated by Knowles (12) dealt with maintenance evaluation and system design management. In considering the evaluation area first, we find three important areas in maintenance system design where evaluation techniques are sorely needed. These areas are (a) evaluation of test logic, (b) evaluation of maintenance system operations, and (c) evaluation of personnel requirements. It is difficult to find anyone who will say how they decide what tests to make in developing confidence and trouble-shooting sequences. Organization and layout of a maintenance operation may be illustrated by the overly-simplified diagrams in Figures 10 and 11.

FUNCTIONAL STATUS DIAGRAM
(FROM REFERENCE 12)

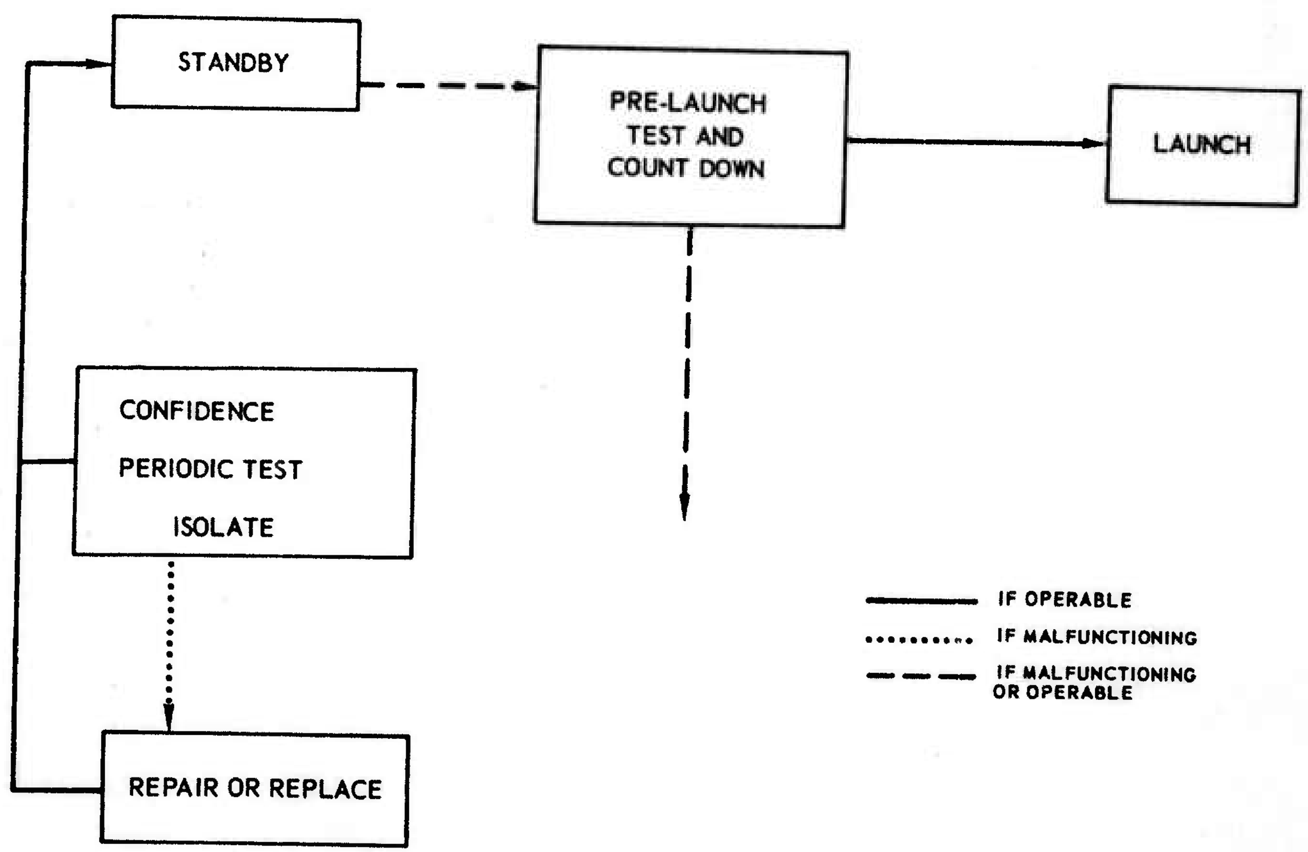

Figure 10

COMPOSITE FUNCTIONAL MAINTENANCE DIAGRAM

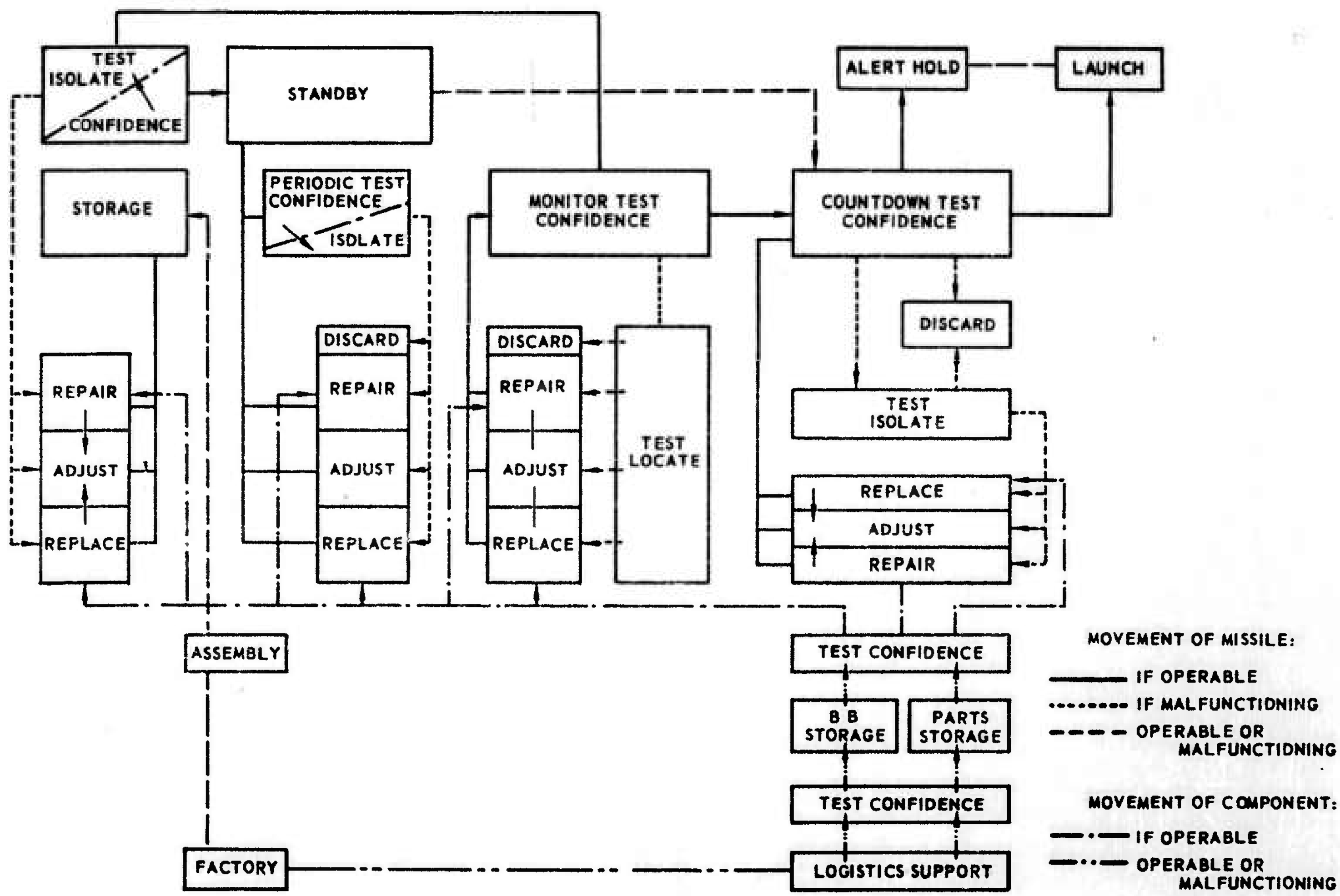

Figure 11

Evaluating personnel requirements is very difficult where we are not selecting men for well-established positions. In this case there are no incumbents to test in order to provide bases for assessing potential applicants. For example, if it is specified that a given job be designed for a level 3 semi-skilled operator with less than a high school education, what does this tell the designer about what can be expected of such a man in the way of adjusting a control, reading displays or analyzing a faulty circuit?

The second area needing further concentrated research has to do with maintenance systems design management. The systems approach is as important to the support system as it is to the prime equipment. We can no longer afford the costly approach of updating an assemblage of experimental support apparatus to create an operational support system. Good system design management requires sound operational objective definition, integration of design in every area, a continuous iteration process of evaluation, redesign and re-evaluation, and effective time phasing and communications among the groups and the customer agencies. Of critical importance to the management picture is recognition of the fact that all aspects of system development must begin at once (this is the concept of concurrency). Consideration of maintenance problems and personnel requirements after other system concepts are fixed leads to costly fixes and inadequate manning provisions. The new concept of early personnel subsystem development and design integration is becoming recognized by top-echelon military management but, as of now, it still remains to be reflected in industry management.

Another consideration to which this study directed its attention concerned use of civilian contract maintenance vs maintenance by military personnel. This question, although not new, has important implications to future maintenance design concepts for ABM systems. A review of instances where civilian vs military maintenance had been compared, brought out several worthwhile and important conclusions:

a) - The military commands recognize that although they would like to have sufficient numbers of skilled technicians within their tables of organization, the likelihood of this being attainable grows dimmer with each successive development. Even within the few specific evaluation reports which were obtainable it was apparent that commands were complaining that the evaluation results were distorted because they could not attain tables of organization strength.

b) - Contract maintenance could be less expensive, on the basis of less manpower.

c) - System effectiveness can be reduced seriously by designing for very low-skill-level maintenance technicians.

d) - The problem of training military technicians is magnified because of age and lack of motivation to remain at the job as a career. Age and experience advantages of contract maintenance personnel could explain the improved maintenance reported in studies which compared military vs civilian maintenance efficiency.

e) - The motivation problem appears to be more easily solved with contract personnel. This is an area of extreme controversy, however. It is frequently stated that contract personnel are more mature, more interested in the professional aspects of their jobs, et cetera. Although investigation of this area was limited in scope, it was apparent that the size of the pay check was an almost overriding factor, especially where contract personnel manned isolated bases.

f) - Large fixed systems which appear to be an accepted part of our defense picture are probably more amenable to contract support than mobile defense or attack systems. During one of the many discussions on this subject a point was made about the motivational aspects, particularly the political and moral issues which might occur. The difficulties of control are potentially much more of a problem with civilians than with military personnel.

It should be obvious from the foregoing comments that this whole area needs further investigation before any general statement could be made. It would seem, however, that the potential rewards for further research might be very worthwhile in terms of allowing greater freedom in establishing design parameters as well as in reducing one of the major cost factors in defense systems, i.e., maintaining them.

A brief mention of a more recent ABM program called the Field Army Ballistic Missile Defense System (FABMDS) should be given at this time, not that such a system will have many maintenance problems which are unique from what we have discussed already, but rather because its problems relate to certain maintenance concepts which vary with types of systems. FABMDS, like other mobile systems (Polaris, for example) may be required to operate for considerable time in isolation from its primary support. The use of a modular maintenance concept has to be weighed against the limited storage capacity of its armored carriers. This same problem confronted the designers of the Polaris system and it was decided that they would be better off with repair capability at the unit level. FABMDS, however, has even a more restricted space problem, so it may be impossible to provide satisfactory facilities for unit repair, particularly under certain field conditions. Combinations of these two concepts are undoubtedly required, but at the present time there are no guides by which these decisions can be made. Perhaps the most important conclusion is to urge designers of future systems to analyze the cost differential between use of expendable modules vs unit repair in light of logistics and environment. An aircraft, for instance, can return to base for replenishment of supplies, whereas a submarine or FABMDS may be isolated for a considerable time period.

No discussion of maintenance would be complete without some projection of the potential role of man in space. Unfortunately, there are but a few individuals considering the maintenance factors of space systems. From most of the studies which have been conducted, the space-borne vehicle has been considered a non-maintainable item once it is launched. However, we were quite interested to note that some sound suggestions are being entertained for use of man in the space vehicle portion of the future systems. Of particular interest is the idea of developing orbiting platforms from which several types of vehicles could be launched. These platforms are proposed more frequently in light of their use for launching lunar or deep space probes. However, the possibilities for use of such bases for maintenance of space-borne ABM systems are extremely interesting to consider. Surveillance satellites, programmed to match orbit with the maintenance base satellite, could relieve the problems often discussed when considering a separate ground-launched maintenance vehicle, i.e., orbit rendezvous. Some of the immediate human factors considerations which become evident in space maintenance are the life support requirements which are necessary to ameliorate the hostile environmental conditions. Over and above this aspect, we must consider ways and means for placing man in a working position, with means of anchoring him to that position. Remotely-controlled tools become an item for more concentrated study, and the matter of handling supplies, parts, fuels, etc., needs to be systematically investigated. A number of people have commented on the advantages of a man in a satellite, even in a research vehicle. For instance, a weather satellite taking pictures exposes many feet of film which cannot be used because its coverage was restricted; that is, an important weather formation was just outside of the pre-set orbit/coverage pattern. The human observer on the other hand, knowing what he is looking for, could re-orient the camera. Human inspectors are difficult to replace in terms of their ability to observe numerous cues and deduce useful conclusions about the condition of an object.

It is further suggested that the space maintenance base could be used for modification of existing systems, and probably at much less cost than launching totally new units. Modification possibilities tie to the human contribution of observing changes in enemy hardware that may also be in space. Several rather crude space tug concepts have been proposed in recent months; however, much needs to be done to look at the entire space maintenance picture in order to determine explicit requirements for such a system, including the possible human role. It is the considered opinion of the authors of this report that future ABM systems must eventually accept a space maintenance requirement in terms of the probable long-term cost payoffs. When they do, certain problem areas must be examined, among which will be the following:

a) - extra-vehicular support (suits, capsules, tugs, etc.)

b) - storage containers for fuels, water, etc.

c) - construction techniques for assembly of materials into usable facilities

d) - space tools for inspection, assembly and adjustment under zero gravity conditions

e) - maintenance space station design, including human engineering of habitable areas as well as exterior configuration

f) - logistics, earth-to-orbit (including packaging of supplies, communications, manning, training, etc.)

g) - psychological factors of motivation, stress, work cycles, personnel rotation, group interaction, and morale

h) - safety in terms of emergency action, treatment of unusual accidents, and design considerations for the physical security of all personnel aboard the station

In summary, it is apparent that maintenance will continue to be an area in future ABM systems where the human role is extremely significant. The readiness factor dictates needs not only for maximum reliability of equipment but also for utmost efficiency on the part of maintenance personnel. Automaticity must be increased, but in turn, those human (manual) tasks which remain must be carefully planned through sound pairing of human capability with design sophistication so that a reasonable selection and training program can be formulated to provide a man-machine combination that will accomplish the desired mission. Manpower requirements for future systems will become even more critical than in the past and it will be important to consider seriously the use of contract personnel who are older, more experienced and proven professionally (13).

CHAPTER VII

SUGGESTED RESEARCH PROBLEM AREAS FOR FUTURE STUDY

This section of the report presents a number of critical problem areas which have received emphasis during the course of the present investigation of man's probable role in future anti-ballistic weapon systems. It is patently obvious that no one group of workers, no matter how sophisticated or well-funded, can come up with a complete listing of the research problems in this broad field. However, the past year's effort of the task group has brought to light a number of gaps in our knowledge about man's function as both a component and a subsystem element, and has focused attention upon some specific problems requiring immediate attention (14, 15).

Since it is probable that all of these areas cannot be investigated during 1961, and even more certain that satisfactory solutions cannot be attained during this period, the following list of research problems is presented in the order of importance that the author of this report believes they demand.

Area 1: Command Performance

It has become increasingly apparent, from analysis of future ABM system requirements, that the role of man as a decision-maker becomes progressively more significant in terms of its consequences as he scales the ladder of command responsibility. At each level of command the tasks involve an increasing set of alternative actions which can be selected, combined, and sequenced in a number of ways. Furthermore, at each successive higher echelon of command the ratio of alternative system configurations which are amenable to pre-programming to all possible configurations becomes progressively smaller. Thus, the top level commander is faced with the paradox of having a requirement for practically all of the raw subsystems data available to him upon demand, and for organizing a command and control system which presents only that information which he is capable of absorbing and acting upon. The amount of information which any one human commander can process per unit time, assuming optimal encoding, is practically microscopic when compared with the avalanche of raw data which may pour into a central storage and processing center.

Two fundamental questions stem from this seeming conflict in requirements: (1) what information must the commander have to make appropriate action decisions, and (2) how should this information be provided (displayed) to him. Patently, the decisions under consideration are based upon a tremendously complex montage of information that should be immediately available in a multitude of forms, i.e., separate pieces, synthesized groups, quantitative, qualitative, historic, predictive, probabilistic,summary, isolated actions magnified, et cetera. This information may be generated by people or machines, from weapons or sensors, about action events or damage to enemy or to self.

This issue is considered by many responsible groups, in both industry and in the military, to be one of the most pressing of all problems facing the system designer (7) and is so broad in scope that only a few specifics can be outlined herein:

A) - At the NORAD COC Level

1) - Are the requirements realistic which presently specify that all or most all of the raw data from more than a dozen subsystems be dumped into NORAD's central data storage and processing system?

2) - How much variability in the output of the NORAD COC for the control of ABM defense forces is attributable to the data presentation portion of the system? How much variability in output may be attributable to the background and training of the commander and how much to prior executive level policy decisions? How much to the possible

consequences stemming from the results of a wrong military decision?

3) - What alternative provisions are being contemplated for graceful system degradation in the event of a communication hiatus between NORAD and its subsystems? If specific questions could be answered with respect to the lower limits of information required for command decisions, what about the feasibility of alternative, possibly mobile, NORAD headquarters configurations?

4) - To what extent does the way in which information is displayed influence the commander's decisions, i.e., to what extent does information content interact with method of display?

5) - What steps can be taken to provide the commander with a validity estimate of the information being displayed?

6) - Does it appear feasible, within the five to ten year time period under consideration, to undertake the development of a second-order computer-director system for NORAD which will reduce the possible alternatives and decisions to a usable decision matrix? This would be accomplished by a computer-aided assessment of pre-programmed action alternatives and consequences, the programming being such that the computer assigns predetermined weights to interactions between alternatives.

B) - At All Echelons

1) - If it is assumed, for purposes of this problem, that decisions occur only after a situation is sufficiently structured to identify an action objective, and that action alternatives are available, then the concept of decision making can be limited to the singular operation of selecting the appropriate alternative with the greatest expected utility, in achieving the desired action objective. The problem, then, has three major aspects:

a) - What information is required for identification of a specific action objective?

b) - Are alternative actions available? Are there time constraints? How many alternatives, et cetera?

c) - What are the expected utility values of alternative courses of action? Can they be reduced to objective measures whose factors are pre-programmable in a computer-aided or other assessment system?

2) - One possible set of operations which defines an action-decision process is shown in Figure 12 (16).

The research problem suggested from this formulation of the action decision process scheme appears straightforward.

Problem: Develop an analytical model based upon this action-decision-process concept and explore its applicability as a guide for specifying design requirements for future computer-aided decision processing subsystems for the ABM command and control function.

Area 2: Decoy Discrimination

Designers of terminal ABM defensive systems have claimed that these weapons could operate in the fully automatic mode in the presence of an unsophisticated ICBM attack. However, a realistic analysis of the threat must assume that a ballistic missile attack would be accompanied by a swarm of decoys (17). It can be expected that these decoys will reach a level of sophistication that will make them almost indistinguishable from warheads. Thus, decoys represent a data processing problem in which a number of discrimination techniques must be employed if the warhead is to be isolated from the decoy cloud. Since, in a computer-aided processing system, each recognized object in the cloud will require independent examination, the question arises as to the time and load constraints within which the system must operate.

The utilization of electronic countermeasures (ECM) which has been suggested many times as a possible enemy threat, plus the likelihood of both extra-atmospheric and re-entry decoy utilization, pose a discrimination problem of the first magnitude. Furthermore, there is

THE ACTION-DECISION PROCESS

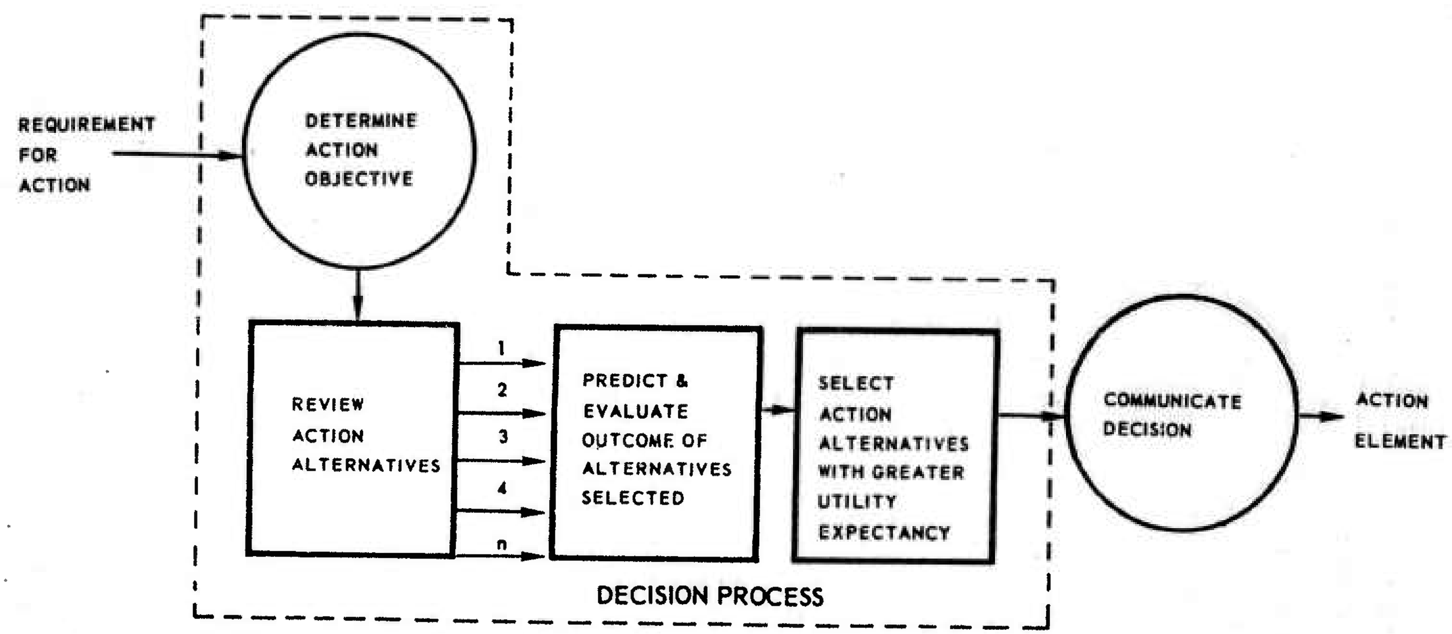

Figure 12

inadequate information on the physical characteristics of the environment in which the warhead and decoys will operate, and not much more information on the differential slow-down characteristics and radar signature of these objects.

All of these factors combine to pose a problem which must be approached from all possible directions, including human-aided techniques. In examining possible decoy-warhead discrimination techniques which presume to utilize the human's unique pattern recognition capabilities, the first issue revolves around the problem of what information should be presented to him. This process is even more complicated than it appears on the surface. We do not even know what to simulate. Without this information, the only recourse (in a laboratory experiment) is to simulate known parameters, which are very sketchy. Such a program would be of marginal utility in isolating those variables which would aid a human in making a discrimination between warheads and decoys, unless by chance the correct variables were selected. Alternately, it might be more productive to conduct actual field tests with live radar and other sensing equipment, monitoring down-range phenomena associated with re-entering nose cones and accompanying tankage fragments.

Even assuming, for the sake of argument, that a human operator could resolve a warhead from a decoy cloud, it is still questionable if he could contribute to the operational effectiveness of an active terminal defense system because of time and traffic problems. Multiple-operator consoles might be an answer to the traffic-handling problem, but a basic issue remains as to the ability of the human to make what is conceivably a very complex judgment within the time limitations imposed upon him by the system configuration.

Successive steps taken in varying the information content of a display intended for human use must proceed on the assumption that somewhere in the mass of data obtained through sensing all known aspects of the incoming cloud there must be some kind of coherent pattern a man can recognize that a computer cannot, at this stage in technology. If this be the case, then through selective manipulation of the available data, those variables may be obtained which are required for man to make operationally effective discriminations. Finally, if the data upon which the discrimination is made can be isolated and quantified, then the process should be amenable to automation.

Problem: Can a human operator, through his unique perceptual capabilities, provide assistance to an active ABM defense system in the task of discriminating between nose cones and decoys through interpretation of information presented on a visual display? A program designed to study this problem would consist of the following steps:

Step 1 - Review the state-of-the-art in decoy and nose cone research and development, and attempt to identify the likely signal parameters that could be obtained via radar and other sensing systems.

Step 2 - Design and build a simulator, incorporating the information obtained in Step 1, which could be utilized in the systematic study of human discrimation capability.

Step 3 - Design and conduct a psycho-physical experiment to evaluate the potential human capability for discriminating between simulated nose cones and decoy signal parameters.

Step 4 - Conduct down-range field tests on live re-entry bodies, utilizing all available sensing systems, as a basis for further validation of laboratory experiments.

Area 3: Electronic Countermeasures (ECM)

One of the more critical problems facing future ABM defense systems will be that of overcoming or countering enemy communications and radar-jamming techniques. It is clear that regardless of radar and communication system performance capabilities in an interference-free environment, performance can be degraded or even rendered ineffective in the presence of enemy jamming. During periods of jamming it may be up to a radar operator to aid the system in seeing through the interference and in retrieving lost target tracks.

In view of the several new requirements levied upon the radar operator, it may be desirable to create a new military occupational specialty, the Electronics Warfare Specialist. In line with this concept, his primary function would be to understand and utilize electronic counter-counter measure (ECCM) techniques in the presence of radar jamming. A major task of the Electronics Warfare Specialist would be to make the information presented to the radar operators under his guidance sufficiently accurate and clear so that the radar operator could perform his normal duties.

Problem: How can the human operator provide the back-up to the ECCM capabilities of communications and data sensing systems through utilization of his ability to recognize patterns and trends in the presence of noise?

An approach to this problem would consist of the following activities:

a) - Analysis of the physical parameters which affect human detection and sorting of complex signals in the presence of jamming.

b) - Through conduct of psycho-physical studies, relate these physical parameters to known human sensory and perceptual capabilities, i.e., signal to noise threshold vs probability of detection.

c) - Through Step 2, above, provide recommendations for further research and development on human-aided ECCM techniques, and develop tentative procedures for the training of Electronics Warfare Specialists.

Area 4: Design for Safety

Since many of the safety rules and procedures applicable to weapon handling and ground support of missile systems are developed as the result of experience and are seldom formally documented, systems designers do not have this information available to them when planning new systems. This lack of integrated documentation is one of the prime causes for repetition and perpetuation of safety design errors which are costly not only in terms of hardware, but also in terms of trained manpower.

Problem: How can planners of ground-based missile systems obtain the information and know-how required for the incorporation of safety features into their designs?

It is suggested that a series of safety manuals, addressed primarily to the ABM system designer and user, be developed in accordance with the following outline:

a) - Conduct a survey of the missile industry and user agencies to collect factual data on operational, test, and design factors related to safety in use, handling, and in maintaining all ground equipments and weapons associated with ABM systems.

b) - Collate this data (Step 1) and develop objective methods for isolating design features and handling procedures which contribute to unsafe conditions, practices, or equipment.

c) - Develop a series of guide manuals which describe in detail the objectives and methods for designing safer equipment, and describe procedures for training personnel in the proper use of equipment to insure safety.

The following are some possible manual topics:

1) - safety in the design and operation of electronic, hydraulic, pneumatic, mechanical, and chemically-powered subsystems

2) - handling of explosives, solid and liquid fuels, toxic materials, and cryogenic materials

3) - handling of radioactive materials and radiation safety precautions

4) - safety problems related to the design of moving equipment, radar antennas, gantrys, hoists, loaders, materials transport, et cetera

5) - safety in complex missile systems maintenance and operation

6) - safety design for systems operation and maintenance under extreme environmental conditions, such as arctic, tropic, desert, and mountain conditions.

Area 5: ABM System Maintainability

In ABM systems of the future, the requirement for the highest attainable degree of maintainability will be second in importance only to operational capability. For maximum effectiveness these systems must have adequate maintenance features designed into them. The combination of maintainability and capability may be referred to as operational effectiveness.

One approach to operational effectiveness is through automation in both data processing and maintenance systems. Demands for further automation point toward fewer people in the maintenance role. However, these individuals may have to be, on the average, more highly skilled. On the other hand, because the demand for technicians is growing faster than the probable supply, personnel of lower native intelligence may have to be used.

Among the more critical problems which will be faced by the military services is that of recruitment and retention of personnel capable of being trained to handle the maintenance problems inherent in complex future ABM systems. It is suggested that answers which may stem from vigorous and timely investigations in the research study areas presented in the following list will make substantial contributions toward a reduction of the personnel problems associated with weapon systems maintenance.

a) - Investigate the fundamental task configurations which make up specific maintenance jobs common to many systems, and measure the time required to perform each task.

b) - Develop more effective means for analysis of maintenance systems utilizing model building techniques which incorporate gaming theory, queing theory, sequential analysis, and other mathematico-deductive methods. Increase research efforts presently underway in development of methods for predicting maintainability. The cost of maintainability has assumed a level which can be even more critical than initial cost and must be accounted for in evaluation of any future ABM system proposal.

c) - Perform a detailed study of the role of the human in satellite systems, particularly as it might be considered in orbital launch operations.

d) - Investigate more thoroughly the use of contract vs military maintenance to determine the basic parameters which can be utilized in making this decision.

As stated earlier in Chapter VI of this report, the concept of maintainability includes more than accessibility, ease of checkout, and simplified trouble-shooting. All the factors that relate to the effectiveness and efficiency with which maintenance can be performed must be considered in advance design for maintenance.

The research problem area covered in Item a) above relates to an alternative approach to the detailed task that must be accomplished for each weapon system development program. These data, if properly collated, could be used by system analysts as well as designers in estimating the impact of a proposed system design on the maintenance requirement and to provide information from which to predict manning, training, and training equipment needs. Hopefully, the collection and collation of maintenance task information on elements and equipments common to many systems would provide a substantial savings in personnel subsystem program development. However, precautions would be necessary to insure that data obtained from a specific system had validity when applied to new designs.

The remaining items in the suggested list of maintenance research problem areas represent study requirements of a more fundamental nature than the relatively pedestrian but necessary task covered in Item a) above. The designer must never overlook the fact, and it is not always obvious, that predicting, describing, and analyzing maintenance requirements and activities is most difficult while equipment is in the predesign stage. This activity often leads to the waste of engineering manpower and project money by making a crucial maintenance design decision based upon sketchy information or errors in judgment concerning the environment in which the system must operate. It is to this general problem that the remaining items in the list were addressed.

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